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Outer Space: What Should Be The United States Government Policy Toward The Region Beyond Earth's Atmosphere?

National Debate Topic For High Schools 1990-1991

Pursuant to Public Law 88-246

Compiled by the Congressional Research Service
Library of Congress

5920-2

PUBLIC LAW 88-246, 88TH CONGRESS, S. 2311,
DECEMBER 40, 1963

AN ACT To provide for the preparation and printing of compilation of materials relating to annual national high school and college debate topics.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Librarian of Congress is authorized and directed to prepare compilations of pertinent excerpts, bibliographical references, and other appropriate materials relating to (1) the subject selected annually by the National University Extension Association and the national high school debate topics and (2) the subject selected annually by the American Speech Association as the national college debate topic. In preparing such compilations the Librarian shall include materials which in his judgment are representative of, and give equal emphasis to, the opposing points of view on the respective topics.

Sec. 2. The compilations on the high school debate topics shall be printed as Senate documents and the compilations on the college debate topics shall be printed as House documents, the cost of which shall be charged to the congressional allotment for printing and binding. Additional copies of such documents may be printed in such quantities and distributed in such manner as the Joint Committee on Printing directs.

Approved December 30, 1963.

CONTENTS

FORWARD V

GENERAL MATERIALS 1

National Space Policy [of President George Bush]. Office of the Press Secretary, The White House. Nov. 16, 1989 3

Weekly Compilation of Presidential Documents, v. 25, July 24, 1989 18

Expanding the Human Frontier--Space and Biotechnology, and the Superconducting Super Collider. Budget of the United States Government, Fiscal Year 1991 21

Outlays and Budget Authority by Agency. Budget of the United States Government, Fiscal Year 1991 30

Space Policy: issue brief, by Marcia S. Smith. Congressional Research Service, 1990 31

The National Space Council, by Patricia E. Humphlett Congressional Research Service, 1989 44

Leadership and America's Future in Space; a report to the Administrator [of NASA], by Dr. Sally K. Ride. Washington, National Aeronautics and Space Administration, 1987 57

Pioneering the Space Frontier: the report of the National Commission on Space. New York, Bantam Books, 1986 86

The NASA Program in the 1990s and Beyond, by David H. Moore. Washington, U.S. Congressional Budget Office, 1988 99

Space Activities of the United States, Soviet Union and Other Launching Countries/Organizations: 1957-1989, by Marcia S. Smith. Congressional Research Service, 1990 160

DEBATE PROPOSITION--RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE SPACE EXPLORATION 239

Beyond Earth's Boundaries: Human Exploration of the Solar System in the 21st Century, 1988 Annual Report to the Administrator [of NASA]; by The Office of Exploration, National Aeronautics and Space Administration. Washington, The Administration, 1988 241

Our Changing Planet: the FY 1991 U.S. Global Change Research Program; a report to accompany the U.S. President's Fiscal Year 1991 Budget, by the Committee on Earth Sciences, Office of Science and Technology Policy, Federal Coordinating Council for Science, Engineering, and Technology. Washington, The Committee, 1990 264

Report of the 90-Day Study on Human Exploration of the Moon and Mars, by the U.S. National Aeronautics and Space Administration. Washington, The Administration, 1989 275

Space Stations: issue brief, by Marcia S. Smith Congressional Research Service, 1990 284

DEBATE PROPOSITION--RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE COMMERCIAL DEVELOPMENT OF SPACE . . . 299

Charting the Course, U.S. Space Enterprise and Space Industrial Competitiveness; highlights of the Report of the Commercial Programs Advisory Committee, A Subcommittee of the NASA Advisory Council. Washington, National Aeronautics and Space Administration, 1989 . . . 301

Report of the Commercial Space Advisory Committee to the Secretary of Commerce. Washington, U.S. Dept. of Commerce, 1989 . . . 306

Space Commerce, an Industry Assessment, by the U.S. Department of Commerce. Washington, The Department, 1988 . . . 346

Centers for the Commercial Development of Space, by the NASA Office of Commercial Programs. Washington, The Administration . . . 410

The Future of the Land Remote Sensing Satellite System (Landsat), by Karl A. Rohrer and Marcia S. Smith. Congressional Research Service, 1989 . . . 430

DEBATE PROPOSITION--RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE ITS MILITARY USE OF SPACE . . . 443

Military Space Forces, the Next Fifty Years, by John M. Collins. Congressional Research Service, 1989 . . . 445

Recommended Changes in U.S. Military Space Policies and Programs; A Paper by the Working Group on Technology, submitted to the Commission on Integrated Long-Term Strategy. Washington, U.S. Department of Defense, 1988 . . . 489

Strategic Defense Initiative: Progress and Promise. Washington, U.S. Department of Defense . . . 500

The Strategic Defense Initiative: Issues for Congress; issue brief, by Steven A. Hildreth. Congressional Research Service, 1990 . . . 515

Ethical and Religious Aspects of SDI: Pro and Con, by Charles H. Whittier, Specialist in Religion and Public Policy. Congressional Research Service, 1987 . . . 530

United Nations General Assembly and Disarmament 1986. New York, United Nations Department for Disarmament Affairs, 1987 . . . 534

Prevention of an Arms Race in Outer Space in Annotated Preliminary list of items to be included in the provisional agenda of the forty-fourth regular session of the General Assembly. New York, United Nations, 1989 . . . 542

Prevention of an Arms Race in Outer Space in Resolutions and Decisions Adopted by the General Assembly during the first part of its Forty-Fourth Session, from 19 September to 29 December 1989; Press Release. New York, United Nations Department of Public Information, 1989 . . . 544

Soviet-U.S. Relations: a briefing book, prepared by the Congressional Research Service. Congressional Research Service, 1990 . . . 547

Arms Control in Space: Workshop Proceedings. Washington, U.S. Congress, Office of Technology Assessment, 1984 . . . 549

AN ANNOTATED BIBLIOGRAPHY ON THE 1988-1989 HIGH SCHOOL DEBATE TOPIC . . . 579

A GUIDE TO INFORMATION SOURCES ON THE 1988-1989 HIGH SCHOOL DEBATE TOPIC . . . 695

AVAILABLE GOVERNMENT PUBLICATIONS ON THE 1988-1989 HIGH SCHOOL DEBATE TOPIC . . . 719

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FOREWORD

The 1990-1991 high school debate topic is: "What Should be the United States Government Policy Toward the Region Beyond Earth's Atmosphere." The three official debate propositions within this topic are:

RESOLVED: That the United States Government should significantly increase space exploration;

RESOLVED: That the United States Government should significantly increase commercial development of space.

RESOLVED: That the United States Government should significantly increase its military use of space.

In compliance with Public Law 88-246, the Congressional Research Service of the Library of Congress prepared this compilation of materials and bibliographic references to assist high school debaters in researching the topic. Excerpts from documents were selected to provide background information, an overview of the principal issues, and a balance of opposing views. We have included some materials that are not readily available in public or research libraries. In selecting items for this reader and bibliography, the Congressional Research Service (CRS) has attempted to sample the wide spectrum of opinions reflected in current literature on these questions. No preference for any policy is indicated by the selection or positioning of articles herein, nor is CRS disapproval of any policy or article to be inferred from its omission.

A research guide is included at the end of this volume; it is intended to help debaters identify further references and organizational resources on their own. Also included is a list of relevant U.S. publications that are available for purchase from the Superintendent of Documents, Government Printing Office. Some of the U.S. Government documents listed in the manual may be found in U.S. Government depository libraries, which can be identified by local public libraries. The Library of Congress cannot distribute copies of these or other materials to debaters.

The documents presented in this compilation were selected by Sherry B. Shapiro, Bibliographic Specialist, Library Services Division, with assistance from Marcia S. Smith, Specialist in Aerospace Policy, and John M. Collins, Senior Specialist in National Defense. Ms. Shapiro also prepared the bibliography and guide to information sources. Production was made possible by John M. White and Ann Eschete, Library Services Division. Robert S. Kirk, B. F. Mangan, and Valentin Leskovsek, also of the Library Services Division assumed additional bibliographic duties during the preparation of this manual. Constance Carter, Head, Reference Section, Science and Technology Division, The Library of Congress, Gary Guenther, of the Economics Division, and John D. Moteff, of the Science Policy Research Division, assisted with review of the bibliography and research guide sections of this manual. Pamela M. Bacon and Lynn Newbill of NASA were extremely helpful in aspects of preparation of this manual and bibliography. Thanks are extended to Kristin M. Vajs, Head, Subject Specialization Section, Library Services Division, and William G. Kaye, of the CRS Review Office, for their review of this product.

Good luck to each debater in researching, preparing, and presenting arguments on this year's topic.

Joseph E. Ross
Director

GENERAL MATERIALS

NATIONAL SPACE POLICY

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release November 16 1989

FACT SHEET
U.S. National Space Policy

On November 2, 1989, the President approved a national space policy that updates and reaffirms U.S. goals and activities in space. The updated policy is the result of a review undertaken by the National Space Council. The revisions clarify, strengthen, and streamline selected aspects of the policy. Areas affected include civil and commercial remote sensing, space transportation, space debris, federal subsidies of commercial space activities, and Space Station Freedom.

Overall, the President's newly-issued national space policy revalidates the ongoing direction of U.S. space efforts and provides a broad policy framework to guide future U.S. space activities.

The policy reaffirms the nation's commitment to the exploration and use of space in support of our national well being. United States leadership in space continues to be a fundamental objective guiding U.S. space activities. The policy recognizes that leadership requires United States preeminence in key areas of space activity critical to achieving our national security, scientific, technical, economic, and foreign policy goals. The policy also retains the long-term goal of expanding human presence and activity beyond Earth orbit into the Solar System. This goal provides the overall policy framework for the President's human space exploration initiative, announced July 20, 1989, in which the President called for completing Space Station Freedom, returning permanently to the Moon, and exploration of the planet Mars.

These and other aspects of U.S. national space policy are contained in the attached document entitled "National Space Policy."

November 2, 1989

NATIONAL SPACE POLICY

INTRODUCTION

This document contains national policy, guidelines, and implementing actions with respect to the conduct of United States space programs and related activities.

United States space activities are conducted by three separate and distinct sectors: two strongly interacting governmental sectors (Civil and National Security) and a separate, non-governmental Commercial Sector. Close coordination, cooperation, and technology and information exchange will be maintained among these sectors to avoid unnecessary duplication and promote attainment of United States space goals.

GOALS AND PRINCIPLES

A fundamental objective guiding United States space activities has been, and continues to be, space leadership. Leadership in an increasingly competitive international environment, does not require United States preeminence in all areas and disciplines of space enterprise. It does require United States preeminence in the key areas of space activity critical to achieving our national security, scientific, technical, economic, and foreign policy goals.

- The overall goals of United States space activities are: (1) to strengthen the security of the United States; (2) to obtain scientific, technological and economic benefits for the general population and to improve the quality of life on Earth through space-related activities; (3) to encourage continuing United States private-sector investment in space and related activities; (4) to promote international cooperative activities taking into account United States national security, foreign policy, scientific, and economic interests; (5) to cooperate with other nations in maintaining the freedom of space for all activities that enhance the security and welfare of mankind; and, as a long-range goal, (6) to expand human presence and activity beyond Earth orbit into the solar system.

- United States space activities shall be conducted in accordance with the following principles:

  -- The United States is committed to the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all mankind. "Peaceful purposes" allow for activities in pursuit of national security goals.

  -- The United States will pursue activities in space in support of its inherent right of self-defense and its defense commitments to its allies.

-- The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right of sovereign nations to acquire data from space.

-- The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.

-- The United States shall encourage and not preclude the commercial use and exploitation of space technologies and systems for national economic benefit. These commercial activities must be consistent with national security interests, and international and domestic legal obligations.

-- The United States will, as a matter of policy, pursue its commercial space objectives without the use of direct Federal subsidies.

-- The United States shall encourage other countries to engage in free and fair trade in commercial space goods and services.

-- The United States will conduct international cooperative space-related activities that are expected to achieve sufficient scientific, political, economic, or national security benefits for the nation. The United States will seek mutually beneficial international participation in space and space-related programs.

CIVIL SPACE POLICY

- The United States civil space sector activities shall contribute significantly to enhancing the Nation's science, technology, economy, pride, sense of well-being and direction, as well as United States world prestige and leadership. Civil sector activities shall comprise a balanced strategy of research, development, operations, and technology for science, exploration, and appropriate applications.

- The objectives of the United States civil space activities shall be (1) to expand knowledge of the Earth, its environment, the solar system, and the universe; (2) to create new opportunities for use of the space environment through the conduct of appropriate research and experimentation in advanced technology and systems; (3) to develop space technology for civil applications and, wherever appropriate, make such technology available to the commercial sector; (4) to preserve the United States preeminence in critical aspects of space science, applications, technology, and manned space flight; (5) to establish a permanently manned presence in space; and (6) to engage in international cooperative efforts that further United States overall space goals.

COMMERCIAL SPACE POLICY

The United States government shall not preclude or deter the continuing development of a separate non-governmental Commercial Space Sector. Expanding private sector investment in space by the market-driven Commercial Sector generates economic benefits for the Nation and supports governmental Space Sectors with an increasing range of space goods and services. Governmental Space Sectors shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with potential commercial applications that preclude or deter Commercial Sector space activities except for national security or public safety reasons. Commercial Sector space activities shall be supervised or regulated only to the extent required by law, national security, international obligations, and public safety.

NATIONAL SECURITY SPACE POLICY

The United States will conduct those activities in space that are necessary to national defense. Space activities will contribute to national security objectives by (1) deterring, or if necessary, defending against enemy attack; (2) assuring that forces of hostile nations cannot prevent our own use of space; (3) negating, if necessary, hostile space systems; and (4) enhancing operations of United States and Allied forces. Consistent with treaty obligations, the national security space program shall support such functions as command and control, communications, navigation, environmental monitoring, warning, surveillance, and force application (including research and development programs which support these functions).

INTER-SECTOR POLICIES

This section contains policies applicable to, and binding on, the national security and civil space sectors.

- The United States Government will maintain and coordinate separate national security and civil operational space systems where differing needs of the sectors dictate.

- Survivability and endurance of national security space systems, including all necessary system elements, will be pursued commensurate with the planned use in crisis and conflict, with the threat, and with the availability of other assets to perform the mission.

IMPLEMENTING PROCEDURES

Normal interagency procedures will be employed wherever possible to coordinate the policies enunciated in this directive.

Executive Order No. 12675 established the National Space Council to provide a coordinated process for developing a national space policy and strategy and for monitoring its implementation.

The Vice President serves as the Chairman of the Council, and as the President's principal advisor on national space policy and strategy. Other members of the Council are the Secretaries of State, Treasury, Defense, Commerce, and Transportation; the Chief of Staff to the President, the Director of the Office of Management and Budget, the Assistant to the President for National Security Affairs, the Assistant to the President for Science and Technology, the Director of Central Intelligence, and the Administrator of the National Aeronautics and Space Administration. The Chairman, from time to time, invites the Chairman of the Joint Chiefs of Staff, the heads of executive agencies and other senior officials to participate in meetings of the Council.

* * * *

POLICY GUIDELINES AND IMPLEMENTING ACTIONS

The following Policy Guidelines and Implementing Actions provide a framework through which the policies in this directive shall be carried out. Agencies will use these sections as guidance on priorities, including preparation, review, and execution of budgets for space activities, within the overall resource and policy guidance provided by the President. Affected Government agencies shall ensure that their current policies are consistent with this directive and, where necessary, shall establish policies to implement these practices.

CIVIL SPACE SECTOR GUIDELINES

- Introduction. In conjunction with other agencies: NASA will continue the lead role within the Federal Government for advancing space science, exploration, and appropriate applications through the conduct of activities for research, technology, development and related operations; National Oceanic and Atmospheric Administration will gather data, conduct research, and make predictions about the Earth's environment; DOT will license and promote commercial launch operations which support civil sector operations.

- Government sectors shall encourage to the maximum extent feasible, the development and use of United States private sector space capabilities.

- A continuing capability to remotely sense the Earth from space is important to the achievement of United States space goals. To ensure that the necessary capability exists, the United States government will: (a) ensure the continuity of LANDSAT-type remote sensing data; (b) discuss remote sensing issues and activities with foreign governments operating or regulating the private operation of remote sensing systems; (c) continue government research and development for future advanced remote sensing technologies or systems; and (d) encourage the development of commercial systems, which image the Earth from space, competitive with, or superior to, foreign-operated civil or commercial systems.

- Assured access to space, sufficient to achieve all United States space goals, is a key element of national space policy. United States space transportation systems must provide a balanced, robust, and flexible capability with sufficient resiliency to allow continued operations despite failures in any single system. The United States government will continue research and development on component technologies in support of future transportation systems. The goals of United States space transportation policy are: (1) to achieve and maintain safe and reliable access to, transportation in, and return from, space; (2) to exploit the unique attributes of manned and unmanned launch and recovery systems; (3) to encourage to the maximum extent feasible, the development and use of United States private sector space transportation capabilities; and (4) to reduce the costs of space transportation and related services.

- Communications advancements are critical to all United States space sectors. To ensure necessary capabilities exist, the United States government will continue research and development efforts for future advanced space communications technologies.

- The United States will consider and, as appropriate, formulate policy positions on arms control measures governing activities in space, and will conclude agreements on such measures only if they are equitable, effectively verifiable, and enhance the security of the United States and our allies.

- All space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness. The United States government will encourage other space-faring nations to adopt policies and practices aimed at debris minimization.

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- Space Science. NASA, with the collaboration of other appropriate agencies, will conduct a balanced program to support scientific research, exploration, and experimentation to expand understanding of: (1) astrophysical phenomena and the origin and evolution of the universe; (2) the Earth, its environment and its dynamic relationship with the Sun; (3) the origin and evolution of the solar system; (4) fundamental physical, chemical, and biological processes; (5) the effects of the space environment on human beings; and (6) the factors governing the origin and spread of life in the universe.

- Space Exploration. In order to investigate phenomena and objects both within and beyond the solar system, NASA will conduct a balanced program of manned and unmanned exploration.

-- Human Exploration. To implement the long-range goal of expanding human presence and activity beyond Earth orbit into the solar system, NASA will continue the systematic development of technologies necessary to enable and support a range of future manned missions. This technology program (Pathfinder) will be oriented toward a Presidential decision on a focused program of manned exploration of the solar system.

-- Unmanned Exploration. NASA will continue to pursue a program of unmanned exploration where such exploration can most efficiently and effectively satisfy national space objectives by among other things: achieving scientific objectives where human presence is undesirable or unnecessary; exploring realms where the risks or costs of life support are unacceptable; and providing data vital to support future manned missions.

- Permanent Manned Presence. NASA will develop the Space Station to achieve permanently manned operational capability by the mid-1990s. Space Station Freedom will: (1) Contribute to United States preeminence in critical aspects of manned spaceflight; (2) provide support and stability to scientific and technological investigations; (3) provide early benefits, particularly in the materials and life sciences; (4) promote private sector experimentation preparatory to independent commercial activity; (5) allow evolution in keeping with the needs of Station users and the long-term goals of the United States; (6) provide opportunities for commercial sector participation; and (7) contribute to the longer term goal of expanding human presence and activity beyond Earth orbit into the solar system.

- Manned Spaceflight Preeminence. Approved programs such as efforts to improve and safely operate the Space Transportation System (STS) and to develop, deploy, and use the Space Station, are intended to ensure United States preeminence in critical aspects of manned spaceflight.

- Space Applications. NASA and other agencies will pursue the identification and development of appropriate applications flowing from their activities. Agencies will seek to promote private sector development and implementation of applications.

  -- Such applications will create new capabilities, or improve the quality or efficiency of continuing activities, including long-term scientific observations.

  -- NASA will seek to ensure its capability to conduct selected critical missions through an appropriate mix of assured access to space, on-orbit sparing, advanced automation techniques, redundancy, and other suitable measures.

  -- Agencies may enter cooperative research and development agreements on space applications with firms seeking to advance the relevant state-of-the-art consistent with United States Government space objectives.

  -- Management of Federal civil operational remote sensing is the responsibility of the Department of Commerce. The Department of Commerce will: (a) consolidate Federal needs for civil operational remote sensing products to be met either by the private sector or the Federal government; (b) identify needed civil operational system research and development objectives; and (c) in coordination with other departments or agencies, provide for the regulation of private sector operational remote sensing systems.

- Civil Government Space Transportation. The unique Space Transportation System (STS) capability to provide manned access to space will be exploited in those areas that offer the greatest national return, including contributing to United States preeminence in critical aspects of manned spaceflight. The STS fleet will maintain the Nation's capability and will be used to support critical programs requiring manned presence and other unique STS capabilities. In support of national space transportation goals, NASA will establish sustainable STS flight rates to provide for planning and budgeting of Government space programs. NASA will pursue appropriate enhancements to STS operational capabilities, upper stages, and systems for deploying, servicing, and retrieving spacecraft as national and user requirements are defined.

- International Cooperation. The United States will foster increased international cooperation in civil space activities by seeking mutually beneficial international participation in civil space and space-related programs. The National Space Council shall be responsible for oversight of civil space cooperation with the Soviet Union. No such cooperative activity shall be initiated until an appropriate interagency review has been completed. United States cooperation in international civil space activities will:

-- United States participation in international space ventures, whether public or private, must be consistent with United States technology transfer laws, regulations, Executive Orders and presidential directives.

-- Support the public, nondiscriminatory direct readout of data from Federal civil systems to foreign ground stations and the provision of data to foreign users under specified conditions.

-- Be conducted in such a way as to protect the commercial value of intellectual property developed with Federal support. Such cooperation will not preclude or deter commercial space activities by the United States private sector, except as required by national security or public safety.

COMMERCIAL SPACE SECTOR GUIDELINES

- NASA, and the Departments of Commerce, Defense, and Transportation will work cooperatively to develop and implement specific measures to foster the growth of private sector commercial use of space. A high-level focus for commercial space issues has been created through establishment of the National Space Council.

- To stimulate private sector investment, ownership, and operation of space assets, the United States Government will facilitate private sector access to appropriate U.S. space-related hardware and facilities, and encourage the private sector to undertake commercial space ventures. Governmental Space Sectors shall:

-- Utilize commercially available goods and services to the fullest extent feasible, and avoid actions that may preclude or deter commercial space sector activities except as required by national security or public safety. A space good or service is "commercially available" if it is currently offered commercially, or if it could be supplied commercially in response to a government service procurement request. "Feasible" means that such goods or services meet mission requirements in a cost-effective manner.

-- Enter into appropriate cooperative agreements to encourage and advance private sector basic research, development, and operations while protecting the commercial value of the intellectual property developed;

-- Provide for the use of appropriate Government facilities on a reimbursable basis;

-- Identify, and eliminate or propose for elimination, applicable portions of United States laws and regulations that unnecessarily impede commercial space sector activities;

-- Encourage free and fair trade in commercial space activities. Consistent with the goals, principles, and policies set forth in this directive, the United States Trade Representative will consult, or, as appropriate, negotiate with other countries to encourage free and fair trade in commercial space activities. In entering into space-related technology development and transfer agreements with other countries, Executive Departments and agencies will take into consideration whether such countries practice and encourage free and fair trade in commercial space activities.

-- Provide for the timely transfer of Government-developed space technology to the private sector in such a manner as to protect its commercial value, consistent with national security.

-- Price Government-provided goods and services consistent with OMB Circular A-25.

NATIONAL SECURITY SPACE SECTOR GUIDELINES

- General:

-- The Department of Defense (DOD) will develop, operate, and maintain an assured mission capability through an appropriate mix of robust satellite control, assured access to space, on-orbit sparing, proliferation, reconstitution or other means.

-- The national security space program, including dissemination of data, shall be conducted in accordance with Executive Orders and applicable directives for the protection of national security information and commensurate with both the missions performed and the security measures necessary to protect related space activities.

-- DOD will ensure that the national security space program incorporates the support requirements of the Strategic Defense Initiative.

- Space Support:

-- The national security space sector may use both manned and unmanned launch systems as determined by specific mission requirements. Payloads will be distributed among launch systems and launch sites to minimize the impact of loss of any single launch system or launch site on mission performance. The DOD will procure unmanned launch vehicles or services and maintain launch capability on both the East and West coasts. DOD will also continue to enhance the robustness of its satellite control capability through an appropriate mix of satellite autonomy and survivable command and control, processing, and data dissemination systems.

-- DOD will study concepts and technologies which would support future contingency launch capabilities.

- Force Enhancement:

-- The national security space sector will develop, operate, and maintain space systems and develop plans and architectures to meet the requirements of operational land, sea, and air forces through all levels of conflict commensurate with their intended use.

- Space Control:

-- The DOD will develop, operate, and maintain enduring space systems to ensure its freedom of action in space. This requires an integrated combination of antisatellite, survivability, and surveillance capabilities.

-- Antisatellite (ASAT) Capability. The United States will develop and deploy a comprehensive capability with programs as required and with initial operations capability at the earliest possible date.

-- DOD space programs will pursue a survivability enhancement program with long-term planning for future requirements. The DOD must provide for the survivability of selected, critical national security space assets (including associated terrestrial components) to a degree commensurate with the value and utility of the support they provide to national-level decision functions, and military operational forces across the spectrum of conflict.

-- The United States will develop and maintain an integrated attack warning, notification, verification, and contingency reaction capability which can effectively detect and react to threats to United States space systems.

- Force Application. The DOD will, consistent with treaty obligations, conduct research, development, and planning to be prepared to acquire and deploy space systems should national security conditions dictate.

INTER-SECTOR GUIDELINES

The following paragraphs identify selected, high priority cross-sector efforts and responsibilities to implement plans supporting major United States space policy objectives:

- Space Transportation Guidelines.

-- The United States national space transportation capability will be based on a mix of vehicles, consisting of the Space Transportation System (STS), unmanned launch vehicles (ULVs), and in-space transportation systems. The elements of this mix will be defined to support the mission needs of national security and civil government sectors of United States space activities in the most cost effective manner.

-- As determined by specific mission requirements, national security space sector will use the STS and ULVs. In coordination with NASA, the DOD will assure the Shuttle's utility to national defense and will integrate missions into the Shuttle system. Launch priority will be provided for national security missions as implemented by NASA-DOD agreements. Launches necessary to preserve and protect human life in space shall have the highest priority except in times of national security emergency.

-- The STS will continue to be managed and operated in an institutional arrangement consistent with the current NASA/DOD Memorandum of Understanding. Responsibility will remain in NASA for operational control of the STS for civil missions, and in the DOD for operational control of the STS for national security missions. Mission management is the responsibility of the mission agency.

-- United States commercial launch operations are an integral element of a robust national space launch capability. NASA will not maintain an expendable launch vehicle (ELV) adjunct to the STS. NASA will provide launch services for commercial and foreign payloads only where those payloads must be man-tended, require the unique capabilities of the STS, or it is determined that launching the payloads on the STS is important for national security or foreign policy purposes. Commercial and foreign payloads will not be launched on government owned or operated ELV systems except for national security or foreign policy reasons.

-- Civil Government agencies will encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services directly from the private sector or with DOD.

-- NASA and the DOD will continue to cooperate in the development and use of military and civil space transportation systems and avoid unnecessary duplication of activities. They will pursue new launch and launch support concepts aimed at improving cost-effectiveness, responsiveness, capability, reliability, availability, maintainability, and flexibility. Such cooperation between the national security and civil sectors will ensure efficient and effective use of national resources.

- Guidelines for the Federal Encouragement of Commercial Unmanned Launch Vehicles (ULVs):

-- The United States Government fully endorses and will facilitate the commercialization of United States unmanned launch vehicles (ULVs).

-- The Department of Transportation (DOT) is the lead agency within the Federal Government for developing, coordinating, and articulating Federal policy and regulatory guidance pertaining to United States commercial launch activities in consultation with DOD, State, NASA, and other concerned agencies. All Executive departments and agencies shall assist the DOT in carrying out its responsibilities, as set forth in the Commercial Space Launch Act and Executive Order 12465.

-- The United States Government encourages the use of its launch and launch-related facilities for United States commercial launch operations.

-- The United States Government will have priority use of government facilities and support services to meet national security and critical mission requirements. The United States Government will make all reasonable efforts to minimize impacts on commercial operations.

-- The United States Government will not subsidize the commercialization of ULVs, but will price the use of its facilities, equipment, and services with the goal of encouraging viable commercial ULV activities in accordance with the Commercial Space Launch Act.

-- The United States Government will encourage free market competition within the United States private sector. The United States Government will provide equitable treatment for all commercial launch operators for the sale or lease of Government equipment and facilities consistent with its economic, foreign policy, and national security interests.

-- NASA and DOD, for those unclassified and releasable capabilities for which they have responsibility, shall, to the maximum extent feasible:

--- Use best efforts to provide commercial launch firms with access, on a reimbursable basis, to national launch and launch-related facilities, equipment, tooling, and services to support commercial launch operations;

--- Develop, in consultation with the DOT, contractual arrangements covering access by commercial launch firms to national launch and launch-related property and services they request in support of their operations;

--- Provide technical advice and assistance to commercial launch firms on a reimbursable basis, consistent with the pricing guidelines herein; and

--- Conduct, in coordination with DOT, appropriate environmental analyses necessary to ensure that commercial launch operations conducted at Federal launch facilities are in compliance with the National Environmental Policy Act.

- Government ULV Pricing Guidelines. The price charged for the use of United States Government facilities, equipment, and service, will be based on the following principles:

-- Price all services (including those associated with production and launch of commercial ULVs) based on the direct costs incurred by the United States Government. Reimbursement shall be credited to the appropriation from which the cost of providing such property or service was paid.

-- The United States Government will not seek to recover ULV design and development costs or investments associated with any existing facilities or new facilities required to meet United States Government needs to which the U.S. Government retains title;

-- Tooling, equipment, and residual ULV hardware on hand at the completion of the United States Government's program will be priced on a basis that is in the best overall interest of the United States Government, taking into consideration that these sales will not constitute a subsidy to the private sector operator.

- Commercial Launch Firm Requirements. Commercial launch firms shall:

-- Maintain all facilities and equipment leased from the United States Government to a level of readiness and repair specified by the United States Government;

-- ULV operators shall comply with all requirements of the Commercial Space Launch Act, all regulations issued under the Act, and all terms, conditions or restrictions of any license issued or transferred by the Secretary of Transportation under the Act.

- Technology Transfer Guidelines.

  -- The United States will work to stem the flow of advanced western space technology to unauthorized destinations. Executive departments and agencies will be fully responsible for protecting against adverse technology transfer in the conduct of their programs.

  -- Sales of United States space hardware, software, and related technologies for use in foreign space projects will be consistent with relevant international and bilateral agreements and arrangements.

- Space Infrastructure. All Sectors shall recognize the importance of appropriate investments in the facilities and human resources necessary to support United States space objectives and maintain investments that are consistent with such objectives. The National Space Council will conduct a feasibility study of alternate methods for encouraging private sector investment, including capital funding, of United States space infrastructure such as ground facilities, launcher developments, and orbital assembly and test facilities.

- The primary forum for negotiations on nuclear and space arms is the Nuclear and Space Talks (NST) with the Soviet Union in Geneva. The instructions to the United States Delegation will be consistent with this National Space Policy directive, established legal obligations, and additional guidance by the President. The United States will continue to consult with its Allies on these negotiations and ensure that any resulting agreements enhance the security of the United States and its Allies. Any discussions on arms control relating to activities in space in forums other than NST must be consistent with, and subordinate to, the foregoing activities and objectives.

* * * *

Remarks on the 20th Anniversary of the *Apollo* Moon Landing

July 20, 1989

Thank you all very, very much. And thank you, Mr. Vice President, for your introduction and for undertaking to head the National Space Council and for already demonstrating your skill for leadership there. And thanks to all of you, who have braved the weather to join us today.

Behind me stands one of the most visited places on Earth, a symbol of American courage and ingenuity. And before me stand those on whose shoulders this legacy was built: the men and women of the United States astronaut corps. And we are very proud to be part of this unprecedented gathering of America's space veterans and to share this stage with three of the greatest heroes of this or any other century: the crew of *Apollo 11*.

It's hard to believe that 20 years have passed. Neil and Buzz, who originated the moonwalk 15 years before Michael Jackson ever even thought of it. [*Laughter*] And Michael Collins, former director of this amazing museum and the brave pilot who flew alone on the dark side of the Moon while Neil [Armstrong] and Buzz [Aldrin] touched down—Mike, you must be the only American over age 10 that night who didn't get to see the Moon landing. [*Laughter*]

And later this evening after the crowd disperses and the Sun goes down, a nearly full Moon will rise out of the darkness and shine down on an America that is prosperous and at peace. And for those old enough to remember that historic night 20 years ago, step outside tonight with your children or your grandchildren, lift your eyes skyward, and tell them of the flag—the American flag—that still flies proudly in the ancient lunar soil. And for those who were not yet born, or then too young to recall, you who are the children of the new century, raise your eyes to the heavens and join us in a great dream, an American dream, a dream without end.

Project *Apollo*, the first men on the Moon—some called it quixotic, impossible—had never been done. But America dreamed it, and America did it. And it began on July 16th, 1969. The Sun rose a second time that morning as the awesome fireball of the Saturn 5 lifted these three pioneers beyond the clouds. A crowd of one million, including half of the United States Congress, held its breath as the Earth shook beneath their feet and our view of the heavens was changed forevermore.

Three days and three nights they journeyed. It was a perilous, unprecedented, breathtaking voyage. And each of us remember the night. Barbara and our daughter, Dorothy, were with me in our red-brick house right here on the outskirts of Washington, where we moved up here to represent Houston in the United States Congress. Our 12-year-old kid, Marvin, was on a trip out West with family friends and remembers stopping at a roadside motel to watch. Second boy, Jeb, 16 that summer, teaching English and listening by radio in a small Mexican village, where electricity had yet to arrive.

The landing itself was harrowing. Alarms flashed, and a computer overload threatened to halt the mission while *Eagle* dangled thousands of feet above the Moon. Armstrong seized manual control to avoid a huge crater strewn with boulders. With new alarms signaling a loss of fuel and the view now blocked by lunar dust, Mission Control began the countdown for a mandatory abort.

America, indeed the whole world, listened—a lump in our throat and a prayer on our lips. And only 20 seconds of fuel remained. And then out of the static came

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the words: "Houston. Tranquility Base here. The *Eagle* has landed."

Within one lifetime, the human race had traveled from the dunes of Kitty Hawk to the dust of another world. *Apollo* is a monument to our nation's unparalleled ability to respond swiftly and successfully to a clearly stated challenge and to America's willingness to take great risks for great rewards. We had a challenge. We set a goal. And we achieved it.

So, today is not only an occasion to thank these astronauts and their colleagues—the thousands of talented men and women across the country whose commitment, creativity, and courage brought this dream to life—it's also a time to thank the American people for their faith, because *Apollo's* success was made possible by the drive and daring of an entire nation committed to a dream.

In the building behind me are the testaments to *Apollo* and to what came before—the chariots of fire flown by Armstrong, Yeager, Lindbergh, and the Wrights. And in the National Archives, across the great expanse of grass, are preserved the founding documents of the idea that made it all possible: the world's greatest experiment in freedom and diversity. And here, standing between these twin legacies, is a fitting place to look forward to the future, because the *Apollo* astronauts left more than flags and footprints on the Moon: They also left some unfinished business. For even 20 years ago, we recognized that America's ultimate goal was not simply to go there and go back but to go there and go on. Mike Collins said it best: "The Moon is not a destination; it's a direction."

And space is the inescapable challenge to all the advanced nations of the Earth. And there's little question that, in the 21st century, humans will again leave their home planet for voyages of discovery and exploration. What was once improbable is now inevitable. The time has come to look beyond brief encounters. We must commit ourselves anew to a sustained program of manned exploration of the solar system and, yes, the permanent settlement of space. We must commit ourselves to a future where Americans and citizens of all nations will live and work in space.

And today, yes, the U.S. is the richest nation on Earth with the most powerful economy in the world. And our goal is nothing less than to establish the United States as the preeminent spacefaring nation.

From the voyages of Columbus to the Oregon Trail to the journey to the Moon itself history proves that we have never lost by pressing the limits of our frontiers. Indeed, earlier this month, one news magazine reported that *Apollo* paid down-to-earth dividends, declaring that man's conquest of the Moon "would have been a bargain at twice the price." And they called *Apollo* "the best return on investment since Leonardo da Vinci bought himself a sketch pad." [*Laughter*]

In 1961 it took a crisis—the space race—to speed things up. Today we don't have a crisis; we have an opportunity. To seize this opportunity, I'm not proposing a 10-year plan like *Apollo*, I'm proposing a long-range, continuing commitment. First, for the coming decade, for the 1990's—Space Station *Freedom*, our critical next step in all our space endeavors. And next, for the new century, back to the Moon. Back to the future. And this time, back to stay. And then a journey into tomorrow, a journey to another planet: a manned mission to Mars.

Each mission should and will lay the groundwork for the next. And the pathway to the stars begins, as it did 20 years ago, with you, the American people. And it continues just up the street there, to the United States Congress, where the future of the space station and our future as a spacefaring nation will be decided.

And, yes, we're at a crossroads. Hard decisions must be made now as we prepare to enter the next century. As William Jennings Bryan said, just before the last turn of the century: "Destiny is not a matter of chance; it is a matter of choice. It is not a thing to be waited for; it is a thing to be achieved."

And to those who may shirk from the challenges ahead, or who doubt our chances of success, let me say this: To this day, the only footprints on the Moon are American footprints. The only flag on the Moon is an American flag. And the know-how that accomplished these feats is American know-how. What Americans dream, Americans can do. And 10 years from now, on the 30th anniversary of this extraordinary and astonishing flight, the way to honor the *Apollo* astronauts is not by calling them back to Washington for another round of tributes. It is to have Space Station *Freedom* up there, operational, and underway, a new bridge between the worlds and an investment in the growth, prosperity, and technological superiority of our nation. And the space station will also serve as a stepping stone to the most important planet in the solar system: planet Earth.

As I said in Europe just a few days ago, environmental destruction knows no borders. A major national and international initiative is needed to seek new solutions for ozone depletion and global warming and acid rain. And this initiative, "Mission to Planet Earth," is a critical part of our space program. And it reminds us of what the astronauts remember as the most stirring sight of all. It wasn't the Moon or the stars, as I remember. It was the Earth—tiny, fragile, precious, blue orb—rising above the arid desert of Tranquility Base.

The space station is a first and necessary step for sustained manned exploration, one that we're pleased has been endorsed by Senator Glenn, and Neil Armstrong, and so many of the veteran astronauts we honor today. But it's only a first step.

And today I'm asking my right hand man, our able Vice President, Dan Quayle, to lead the National Space Council in determining specifically what's needed for the next round of exploration—the necessary money, manpower, and materials, the feasibility of international cooperation, and develop realistic timetables, milestones along the way. The Space Council will report back to me as soon as possible with concrete recommendations to chart a new and continuing course to the Moon and Mars and beyond.

There are many reasons to explore the universe, but 10 very special reasons why America must never stop seeking distant frontiers: the 10 courageous astronauts who made the ultimate sacrifice to further the cause of space exploration. They have taken their place in the heavens so that America can take its place in the stars.

Like them, and like Columbus, we dream of distant shores we've not yet seen. Why the Moon? Why Mars? Because it is humanity's destiny to strive, to seek, to find. And because it is America's destiny to lead.

Six years ago, *Pioneer 10* sailed beyond the orbits of Neptune and of Pluto, the first man-made object to leave the solar system. Its destination unknown. It's now journeyed through the tenures of five Presidents—four billion miles from Earth. In the decades ahead, we will follow the path of *Pioneer 10.* We will travel to neighboring stars, to new worlds, to discover the unknown. And it will not happen in my lifetime, and probably not during the lives of my children, but a dream to be realized by future generations must begin with this generation. We cannot take the next giant leap for mankind tomorrow unless we take a single step today.

To all of you here, our able director of NASA and others who've served so well—to all of you here—and especially the astronauts, we wish you good luck in your quests, wherever that may take you. Godspeed to you, one and all, and God bless the United States of America. Thank you all very, very much.

Note: The President spoke at 10:30 a.m. on the steps of the Smithsonian National Air and Space Museum. In his closing remarks, he referred to Richard H. Truly, Administrator of the National Aeronautics and Space Administration. Before making his remarks, the President viewed the Apollo 11 lunar module in the museum. Following his remarks, he participated in the unveiling of a stamp commemorating the Apollo 11 Moon mission.

III.B. EXPANDING THE HUMAN FRONTIER—SPACE AND BIOTECHNOLOGY, AND THE SUPERCONDUCTING SUPER COLLIDER

Since the beginning of civilization, humankind has sought to explore the frontier and increase its knowledge of the world. Humans have endeavored to discover the innermost secrets of living cells, indeed, to discover what particles make up all matter; and to explore our world from the deepest oceans to the outermost boundaries of our solar system and beyond. Today there are unprecedented opportunities to expand the frontier of knowledge and to expand human presence and activity. The budget places a priority on three of the most exciting frontiers now being explored: space, to unlock the secrets of the universe; biotechnology, to unlock the secrets of life itself and apply them for the benefit of all; and high-energy physics, including the development of the Superconducting Super Collider, to unlock the secrets of matter and energy.

EXPANDING THE HUMAN FRONTIER—FUNDING SUMMARY

(Dollar amounts in millions)

	Budget Authority			
	1990 enacted	1991 proposed	Dollar change	Percent change
Understanding and Exploring Space: NASA	12,323	15,239	+2,916	+24
Improving Productivity and Quality of Life: Biotechnology	3,364	3,578	+214	+6
Unlocking the Secrets of Matter and Energy: High Energy Physics and the Superconducting Super Collider	1,139	1,315	+176	+15

UNDERSTANDING AND EXPLORING SPACE: NASA

The exploration of space has benefits for the United States that go far beyond the quantifiable. There are specific payoffs in the form of new materials, technological discoveries and microgravity research. The eventual commercialization of space will stimulate economic growth and improved life on Earth. But no price can be put on the lifting of the spirit of people everywhere, like that which occurred at the time of the Apollo landings on the Moon. No value can be calculated for the wonder engendered by the pictures of Jupiter, Saturn, Uranus and, in August of 1989, of Neptune sent back over millions of miles by Voyager. And no quantitative measure of any kind can capture the benefit of expanding human horizons, human dreams, and the human domain.

The key to developing space successfully will be stable and sustainable funding for a balanced Federal program of science, applications, and manned space activities, coupled with encouragement by the government of develop-

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Washington, For Sale by the Supt. of Docs., G.P.O., 1990. p. 49-58.

ment by the private sector of the commercial potential of space. The 1991 budget is concrete evidence of the firm commitment by the President to a continuing, active and exciting American presence in space—indeed, to America's leadership in space science and exploration.

The 1991 budget proposes to allocate $15.8 billion for space activities, including $15.2 billion for the National Aeronautics and Space Administration (NASA), an increase of $2.8 billion or 22 percent. NASA's total budget of $15.2 billion represents an increase of $2.9 billion or 24 percent over 1990. This is the largest increase for any major agency of the Government. It represents a commitment to a brighter future.

THE U.S. CIVIL SPACE PROGRAM

The U.S. civil space program has made major advances and achieved stunningly ambitious goals since it was created four decades ago.

In unmanned planetary exploration, U.S. spacecraft have made essentially a "grand tour" of the major planets in our solar system and have landed unmanned vehicles on Mars to explore its surface. In astronomy, U.S. orbiting observatories have given us a window on the stars and into the creation of the universe. This window will be enlarged, by several orders of magnitude, with the long-awaited launch in 1990 of the first of the orbiting "Great Observatories", the Hubble Space Telescope. Earth observations satellites have given us a wealth of information about our planet—information that will assist us in understanding and solving our most serious environmental problems.

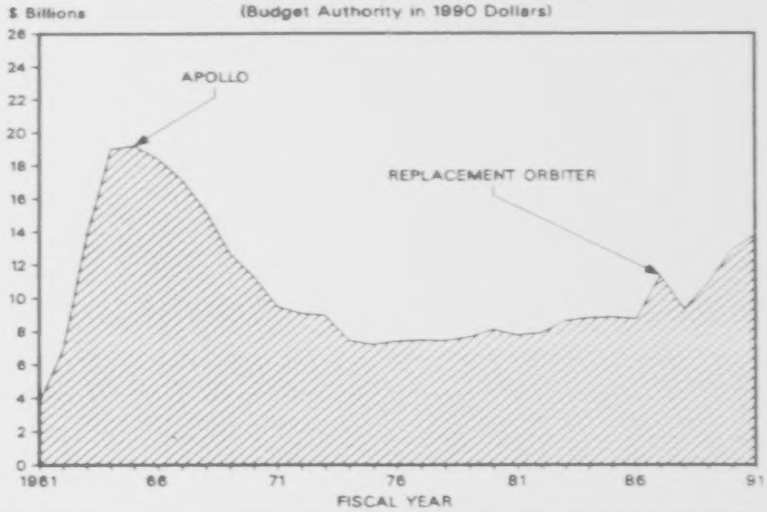
In 30 years, the progress of manned space flight has been truly amazing: the time from the first suborbital flight by Alan Sheppard to the first steps by humans on another heavenly body—the Moon—was less than a decade. This was followed by the development of the world's only manned reusable space vehicle, the Space Shuttle. This versatile vehicle can launch satellites, retrieve satellites for repair, and be used as an orbiting laboratory. Today, the United States, with its international partners, is developing the Space Station Freedom, which—when it is launched in the mid-1990s—will be the world's first permanently-manned microgravity and life sciences laboratory. It will eventually have the capability to service satellites in orbit and to serve as a way station on the journey to the Moon and Mars. Despite these remarkable successes, the United States has reduced over time its funding of the space program. The following chart illustrates the historical pattern of Federal funding for NASA.

As the figure shows, funding for space activities rose and fell precipitously during the Apollo era, then remained level during the 1970s. Funding for space activities is now rising again with the resumption of Space Shuttle flights and with the development of Space Station Freedom. Funding for space science has remained relatively stable over this period, with some increases in recent years.

The benefits of space for the U.S. economy and society are numerous and substantial. For example, the satellite communications industry is a direct result of the development of space communications technology. "Live via satellite" would not be possible today without the early Federal investment in space. As evidenced by a wide variety of other advances—from new lightweight materials for aerospace and other applications, to life-saving breathing equipment used by firemen, to long-lived, micro-miniaturized electronics now used in medical equipment such as pacemakers—the space program continues to create new business opportunities and to contribute to the economy.

SPACE AND THE 1991 BUDGET

The 1991 budget provides major increases for space activities—including research, development, and operations—to meet four broad objectives, all of which are important to maintaining the Nation's world space leadership. These areas are: (1) building transportation infrastructure; (2) expanding the space frontier through manned exploration; (3) using space to increase our scientific understanding; and (4) developing the commercial potential of space. The following table shows the level of funding proposed in the 1991 budget for each of these four objectives, as well as for Space Station Freedom (which supports all of the objectives) and for operational activities.



IN REAL TERMS, NASA'S BUDGET HAS BEEN REDUCED SINCE THE MID-1960'S

(Budget Authority in 1990 Dollars)

THE BUDGET CALLS FOR A 22 PERCENT INCREASE FOR FEDERAL CIVIL SPACE ACTIVITIES

(Dollar amounts in millions)

Objective	Budget Authority			
	1990 estimate	1991 proposed	Dollar change	Percent change
Building transportation infrastructure	7,182	8,236	+1,054	+15
Expanding the space frontier through manned exploration	859	1,267	+408	+47
Using space to increase our scientific understanding	2,718	3,311	+593	+22
Space Station Freedom	1,928	2,627	+699	+36
Developing the commercial potential of space	61	106	+44	+72
Federal operational activities	243	258	+15	+6
Total, all agencies	12,991	15,805	+2,813	+22
Total, NASA	12,322	15,239	+2,917	+24

Building Aeronautics and Space Transportation Infrastructure

The National Space Policy mandates that the nation maintain a balanced and flexible space transportation infrastructure. No other space objective would be achievable without safe, reliable space transportation. Historically, the Federal Government has developed, built, maintained and operated the nation's space transportation systems—both expendable launch vehicles and the Space Shuttle. Today, however, that is changing. Commercial firms are providing expendable launch vehicle services for both government and commercial payloads. The following table illustrates the level of Federal funding proposed for fiscal year 1991 to meet the space transportation objective.

The budget proposes funding for Space Shuttle production and operations of $4.2 billion, an increase of $752 million, or 22 percent, over 1990. This funding will support the launch, mission, and landing operations for 10 Shuttle flights planned for 1991, plus the continued acquisition of long-lead spare parts, and support for Shuttle payloads.

THE BUDGET INCLUDES FUNDING FOR 10 SHUTTLE FLIGHTS IN 1991

(Dollar amounts in millions)

	Budget Authority			
	1990 estimate	1991 proposed	Dollar change	Percent change
Space Shuttle production/Shuttle improvements	1,120	1,302	+183	+16
Space Shuttle operations	2,319	2,889	+571	+25
Space transportation capability development	504	683	+179	+36
Expendable launch vehicle (ELV) services [1]	98	131	+33	+34
Tracking and data acquisition	1,096	1,002	−94	−9
Aeronautics R&D [2]	450	512	+62	+14
Facilities and program management	1,596	1,716	+120	+8
Total	7,182	8,236	+1,054	+15

[1] Excludes ELV's being purchased in support of robotic science missions for exploration.

[2] Excludes R&D for the National Aerospace Plane program.

The Space Shuttle.—The Space Transportation System (STS) is composed of the Space Shuttle fleet, currently three orbiters with a fourth under construction, and the associated infrastructure (such as launch pads, communications and tracking, and orbiter processing and assembly facilities). The Shuttle is the most versatile space launch vehicle in the world. It is a reusable, multipurpose vehicle that launches and retrieves satellites, and provides an orbiting laboratory for microgravity and life sciences. Techniques for manufacturing commercially-valuable products, such as medical diagnostics and therapeutics, have been tested successfully aboard the Shuttle.

However, the Shuttle is also very complex and expensive to operate. For example, the three main engines of the Shuttle have many thousands of moving parts, each of which must function perfectly during each launch. In order to support its reusable elements, the STS requires a large infrastructure, both facilities and personnel, to maintain and operate it.

Prior to the Challenger accident, funding for the R&D associated with improvements in space transportation was declining and funding for operations was increasing as the number of Shuttle missions increased. The Challenger accident made it clear that continued funding for R&D to maintain and improve the safety, reliability and performance of the

Shuttle is vital. This fact is reflected in the 1991 budget by the continuation of the Advanced Solid Rocket Motor program, which will develop and produce a new, more reliable generation of solid rockets, and by continued funding of other necessary Shuttle improvements, such as the Advanced Turbopump for the Shuttle main engine. Within the total for Shuttle Production, the budget proposes $947 million for these elements, an increase of $165 million over 1990.

Expendable Launch Vehicles (ELVs).—The National Space Policy requires that civil Federal agencies encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services from the private sector. This policy not only encourages and supports the growing commercial space launch industry, but also ensures the availability of a balanced and cost-effective mix of space launch vehicles. NASA no longer maintains or operates its own ELVs. In 1991, NASA will continue the purchase of ELV services for a number of important science payloads, including the Comet Rendezvous/Asteroid Flyby and Cassini missions.

Aeronautics R&D.—The goal of NASA's aeronautical R&D program is to conduct research and develop technology to strengthen U.S. leadership in civil and military aviation. NASA also operates unique aeronautical research and testing facilities. The 1991 budget reflects a strong program of fundamental research and technology, including the continuation of efforts aimed at resolving critical environmental issues associated with high-speed flight. In addition, NASA will continue the five-year wind tunnel revitalization program to modernize NASA's major wind tunnels for productive use well into the next century.

Expanding the Space Frontier Through Manned Exploration

The President has proposed that the United States undertake an ambitious mission of manned exploration of the solar system. This will not be a journey of 10 or even 20 years, but one that will continue for decades, perhaps even centuries. This journey will require a long-term commitment—of resources, both financial and human, and of national will.

The Government has taken the first step toward expanded manned exploration with the development of Space Station Freedom. The 1991 budget also funds a new initiative to support the robotic science missions and to develop the "pacing technologies" that will be needed in the coming decade to enable the next steps in the journey. Over the coming months and years, the National Space Council will be coordinating the development of the overall strategy for pursuing the goal of space exploration.

Space Station Freedom.—Space Station Freedom will serve a wide variety of purposes: it will be a microgravity and life sciences laboratory, a testbed for new technologies in areas such as life support and robotics, a platform for astronomical and Earth observations, and a node for on-orbit servicing of satellites. Freedom will also be the cornerstone of the President's exploration initiative in the next decade. Assembling and operating Freedom in space will produce advances in knowledge about how man can live and work in space for long, continuous periods of time. This knowledge is critical for any future journeys.

For 1991, the budget proposes a total of $2,627 million to continue Space Station Freedom. This is an increase of $699 million, or 36 percent above 1990. It will provide for the critical transition from design to actual fabrication of the first long-lead time hardware elements.

CONSTRUCTION WILL BEGIN ON SPACE STATION FREEDOM IN 1991

(Dollar amounts in millions)

	Budget Authority			
	1990 estimate	1991 proposed	Dollar change	Percent change
Space Station Freedom:				
Research and development	1,750	2,431	+681	+39
Facilities and program management	178	196	+18	+10
Total, Space Station Freedom	1,928	2,627	+699	+36

Freedom is being developed with our international partners and is the largest international R&D project ever undertaken. Over the past several months, the program has been revised as it became clear that the Congress would not provide the resources that the President requested for 1990. The result of this re-evaluation has been to delay the availability of some capabilities (e.g., satellite servicing) until the Space Station is completely assembled, and to eliminate some high development cost items (e.g., all A-C power system). The revised schedule calls for the first element launch in 1995, permanently manned capability in 1997 and completion of assembly in 1999. NASA is now conducting an analysis of how Freedom can be best used to support the President's exploration initiative.

Expanding the Space Frontier Through Manned Exploration: the Mission Back to the Moon and to Mars.—The President has lifted the sights of the space program with his call for the establishment of a manned presence on the moon and a manned mission to Mars. The budget reflects the Administration's commitment to this mission by proposing an increase of $408 million, or 47 percent above fiscal year 1990 levels, for space exploration activities. The budget includes major increases for launching robotic science missions, accelerating the development of the technology and advanced launch systems to support expanded exploration, and proceeding with technology development for the National Aerospace Plane (NASP).

A 47 PERCENT INCREASE FOR EXPLORATION ACTIVITIES WILL SUPPORT THE MOON/MARS INITIATIVE

(Dollar amounts in millions)

	Budget Authority			
	1990 estimate	1991 proposed	Dollar change	Percent change
Expanding Exploration of Space:				
Robotic Science Missions:				
Life sciences	50	80	+30	+60
Unmanned Moon-Mars missions	187	228	+41	+22
Technology Development:				
Space power (SP-100):				
National Aeronautics and Space Administration	10	30	+20	+200
Department of Defense	20	20	—	—
Department of Energy	30	51	+21	+70
Subtotal, SP-100	60	101	+41	+68
Advanced Launch System:				
National Aeronautics and Space Administration	—	44	+44	N.A.
Department of Defense	111	85	−26	−23
Subtotal, Advanced Launch System	111	129	+18	+16
Other Technology Development	191	386	+195	+102
Mission studies	(15)	37	+22	+147
National Aerospace Plane:				
National Aeronautics and Space Administration	59	119	+60	+102
Department of Defense	192	158	−34	−18
Subtotal, National Aerospace Plane	251	277	+26	+10
NASA Facilities and Program Management	9	28	+19	+211
Total, Exploration Initiative	859	1,267	+408	+47

N.A. Not applicable.

Robotic Science Missions.—Prior to initiating a manned mission to the Moon or Mars, important information must be gathered about those bodies—their surfaces, the atmosphere of Mars—so that manned missions can be carried out with maximum safety and effectiveness. This information is best obtained with robotic science missions. The 1991 budget proposes a significant enhancement for the Mars Observer, scheduled for launch in 1992. This enhancement will support the modification of systems and software to provide upgraded high-resolution image processing and allow more information on the Martian surface and atmosphere to be sent back to Earth. In addition, the budget provides funding to complete the definition studies and cost analyses for a new mission, the Lunar Observer, which would be initiated in 1992 for a 1996 launch date. Modeled after the Mars Observer, the Lunar Observer will provide valuable information about areas of the Moon never before examined.

Life sciences represent another critical area of research that must be undertaken in order to understand and potentially counteract the effects of long-term space flight on humans. The 1991 budget proposes $80 million for biological and space biomedical research. Within this total, funding will be provided to complete the definition for the Lifesat program. Lifesat will be a series of reuseable satellites designed to carry living specimens into orbit, to monitor and study critical parameters such as radiation exposure, and to return the living specimens to Earth for analysis. Following the completion of definition in 1991, Lifesat development will be initiated in 1992 with the first launch in 1994.

Developing New Technologies for the Future.—There are a number of technology areas that must be investigated if future missions to the Moon and Mars are to be undertaken. These "pacing" technologies include transportation, space power, and life support. The 1991 budget proposes to increase ongoing technology development programs in transportation and space power, and to make additional investments in new areas such as nuclear propulsion and life support.

- Transportation.—The technologies inherent in the Shuttle and in the current generation of ELVs are now between 20 and 40 years old. In addition, both the Shuttle and current ELVs emphasized performance over cost-effectiveness. Thus, there is little chance of significantly reducing the cost-per-pound to Low-Earth-Orbit without major advances in launch vehicle technology. More cost-effective transportation systems would lower the cost of any future exploration initiative. In addition, lower cost, reliable transportation systems will be needed if the private sector is ever to fully exploit the benefits of space.

  To address these issues, the 1991 budget proposes $277 million in total ($119 million for NASA and $158 million for DOD) for the continued development of the National Aerospace Plane (NASP), a joint NASA-DOD project that will develop and demonstrate technologies for hypersonic flight, including single-stage-to-orbit. The 1991 budget also proposes $129 million for both NASA and DOD to continue their technology development for the Advanced Launch System (ALS). The ALS technology program will define concepts and develop technology applicable to a new family of launch vehicles. The long-term goal of the program is to produce a family of lower-cost, reliable and flexible launch vehicles.

- Space Power.—More efficient and high-energy power sources that are not dependent on sunlight will be necessary both for long-term missions in space and for manned bases on planetary surfaces. One option is nuclear power. The SP-100 program being carried out jointly by NASA and the Departments of Defense and Energy is designed to test the concept of the generation of electricity by a nuclear reactor for space applications. The budget proposes to increase funding for SP-100 by 68 percent, to a total of $101 million.

- Other Technologies.—There are a number of other important technologies in which investments must be made now to support the exploration initiative. These technologies have the potential to significantly reduce the cost and risk of future manned exploration. Among these are propulsion, including nuclear propulsion, life support, and flexible structures (both in space and on planetary surfaces). The 1991 budget proposes funding of $386 million for these technologies, more than double the 1990 level. Within this total, NASA will initiate a new effort to seek innovative technological approaches to the challenges of manned space exploration. In addition, the agency will be reviewing its current technology programs with the intent of revising and refocusing these programs to support the President's goals.

Using Space to Increase Scientific Understanding

Perhaps the greatest benefit derived to date from our space activities is the United States' strong and continuing tradition of world leadership in space science—most recently and vividly demonstrated by the Voyager Neptune encounter in 1989. The U.S. and the world space science communities are anticipating an exciting new era of space science missions for planetary exploration, astronomy and Earth observations over the next decade. The budget proposes to increase funding for these activities by $593 million, or 22 percent, over 1990 levels.

USING SPACE TO INCREASE SCIENTIFIC UNDERSTANDING

(Dollar amounts in millions)

	Budget Authority			
	1990 estimate	1991 proposed	Dollar change	Percent change
Physics and astronomy	861	985	+124	+14
Planetary exploration	278	382	+104	+37
Earth observations:				
Earth observation system precursors	415	376	-39	-9
Earth probes	—	25	+25	N.A.
Earth observation system (EOS)	—	235	+235	N.A.
Subtotal, Earth observations	415	636	+221	+53
Other science programs	506	559	+53	+10
Facilities and program management	658	749	+91	+14
Total	2,718	3,311	593	22

N.A. Not applicable.

This new era of space science advancement has already begun with the successful launches in 1989 of the Magellan mission to Venus, the Galileo mission to Jupiter, and the launch of the Cosmic Background Explorer aboard an ELV. Activities planned in 1990 include the planned launches of the Hubble Space Telescope and the Gamma Ray Observatory, two of the "Great Observatories", and the international Ulysses mission to explore the Sun.

The 1991 budget will also allow for the continuation of the development of important projects such as the Advanced X-ray Astrophysics Facility, planned for launch in 1995, the Comet Rendezvous/Asteroid Flyby and the Cassini mission to Saturn. The budget will also provide support for thousands of researchers and students to acquire and analyze data from previously launched missions.

Understanding and Observing Global Change

Earth Observations.—The budget proposes over $1 billion for all agencies to extend U.S. leadership in understanding global environmental change. This represents a 57 percent increase over 1990. There are a number of NASA activities that will make major contributions to the U.S. Global Change Research Program (USGCRP). This coordinated multi-agency program is the world's most ambitious global change research effort. At the Paris Economic Summit, the President asked the other industrialized nations to join the U.S. in this endeavor. The complementary space-based and ground-based research and observation effort is designed to develop the knowledge and data needed to support and improve policy decision-making on issues related to global change (e.g., global warming, ozone depletion). (The USGCRP is also discussed in the sections on Enhancing Research and Development, and Protecting the Environment).

NASA is a major participant in the USGCRP through its Mission to Planet Earth. NASA will develop and launch a number of satellites and instruments, including TOPEX (to analyze surface ocean circulation) and the Upper Atmosphere Research Satellite (UARS) (to analyze the chemistry of the upper atmosphere). The 1991 budget proposes a major new program, the Earth Observing System (EOS), which is a series of space-based instruments and platforms, developed by the U.S., the Europeans and the Japanese. EOS will be critical to improving our understanding of Earth processes and global change since it will provide the first opportunity to collect data simultaneously on a multitude of different features of the planet's environment.

The 1991 budget proposes development of two series of Earth-orbiting platforms, each of which will have a number of instruments designed to collect a broad spectrum of environmental data related to global change (including global warming, drought and other phenomena). The first platform is planned for launch in 1998. In addition, NASA will continue to develop a comprehensive data management system (EOSDIS) that will support a wide range of research focused on studying Earth as an integrated system, and will ensure that scientists have timely access to Earth observations data.

In addition to EOS, the 1991 budget will initiate the development of Earth Probes, a series of smaller instruments focused on specific, high-priority data needs, including ozone depletion. The first Earth Probe will be launched in 1994. Along with TOPEX and UARS, Earth Probes will provide significant near-term scientific benefits, and will enable the testing and validation of EOSDIS before the launch of the first EOS platform.

Developing the Commercial Potential of Space

The commercial space industry today consists primarily of communications satellite manufacturers (which is a stable mature sector) and launch service providers (which is a new sector). There are also selected commercial efforts in areas such as microgravity. The commercial space industry represents a promising outgrowth of the nation's space program.

The commercial space industry has grown rapidly and has drawn hundreds of millions of private sector dollars into private space endeavors. For example, there are now many commercial launch providers and new launch vehicles, based on new design concepts such as air-launched systems and hybrid engine designs, being developed by firms willing to shoulder the risks of space. In addition, states such as Hawaii and Florida have started investing their own funds in the development of commercial space launch infrastructure.

As overseer of the growing commercial space transportation industry, the Department of Transportation (DOT) is responsible for identifying and changing government policies and regulations that inhibit the development of a robust commercial launch sector and for regulating and licensing commercial launches and launch sites. DOT now cites over 33 U.S. and foreign commitments to launch satellites on U.S. commercial launch vehicles.

The 1991 budget will continue the Administration's strong support for the commercialization of space. NASA will allocate $229 million to continue to procure all of its expendable launch vehicle services from private launch service providers. In addition, the budget will provide $101 million for NASA's Office of Commercial Programs, including new funding for a special initiative through its Centers for the Commercial Development of Space (CCDSs) to provide flight opportunities for innovative experiments in microgravity. The CCDSs are cooperative ventures between universities and companies that investigate and develop new commercial uses of space. The 1991 budget also provides nearly a 7 percent increase, to a total of $4.5 million, for DOT's Office of Commercial Space Transportation.

Federal Operational Activities

The 1991 budget proposes $258 million for the Department of Commerce satellite programs. This includes $174 million for the development and launch of replacement satellites for the current polar-orbiting and geostationary weather satellite systems and $47 million to operate those systems. The Administration is committed to operating the Land Remote Sensing Satellites (Landsats) currently in orbit (Landsats 4 and 5) as long as they function, and to completing the development and launch of the next satellite (Landsat 6). For 1991, $37 million is requested for the launch of Landsat 6. No funds are proposed for the operation of Landsat 6 because these costs will be borne by the contractor, the Earth Observation Satellite Company. No further funding is requested for Landsats 4 and 5 because these satellites are expected to cease operating in 1990.

The Administration is considering options for continuing Landsat-type data after Landsat 6. No funds are required in 1991 for additional satellites, consistent with the expected lifetime of Landsat 6. The National Space Council will conduct a review of the management and configuration of a follow-on system, and will report expeditiously to Congress on the outcome of its deliberations.

Table 4.1—OUTLAYS BY AGENCY: 1983–1995

(in millions of dollars)

Department or other unit	1983	1984	1985	1986	1987	1988	1989	1990 estimate	1991 estimate	1992 estimate	1993 estimate	1994 estimate	1995 estimate
Legislative Branch	1,437	1,579	1,610	1,665	1,812	1,852	2,095	2,317	2,678	2,765	2,714	2,827	2,833
The Judiciary	787	866	966	1,069	1,178	1,337	1,492	1,701	2,028	2,223	2,289	2,351	2,409
Executive Office of the President	94	95	111	107	108	121	124	174	319	408	375	382	395
Funds Appropriated to the President	7,878	10,837	11,858	11,042	10,406	7,253	4,280	9,162	12,188	13,227	12,479	12,538	13,253
Agriculture	52,404	42,015	55,523	58,679	49,600	44,003	48,316	48,246	48,715	50,304	48,652	47,809	47,384
Commerce	1,925	1,894	2,140	2,083	2,127	2,279	2,571	3,861	2,771	2,655	2,650	2,558	2,296
Defense-Military	204,410	220,928	245,154	265,480	273,966	281,935	294,880	286,791	292,145	296,943	299,035	302,310	304,842
Defense-Civil	18,891	19,540	18,770	20,254	20,684	22,029	23,450	24,751	25,517	26,620	27,737	28,834	29,944
Education	14,558	15,511	16,682	17,673	16,800	18,246	21,608	22,316	23,711	24,054	24,146	24,295	24,488
Energy	10,590	10,991	10,587	11,026	10,683	11,166	11,387	12,290	13,438	15,732	16,509	17,203	17,682
Health and Human Services-except social security	125,941	121,082	132,104	143,253	148,893	159,071	172,301	191,174	204,082	222,615	241,236	262,921	283,908
Health and Human Services-soc. sec.	150,731	171,167	183,434	190,684	202,422	214,489	227,473	244,587	260,089	275,302	291,741	308,185	324,579
Housing and Urban Development	15,814	16,663	28,720	14,139	15,484	18,938	19,680	22,882	23,023	23,873	24,766	25,033	26,052
Interior	4,552	4,947	4,825	4,789	5,050	5,147	5,213	5,832	5,698	5,686	5,780	5,811	5,715
Justice	2,849	3,184	3,586	3,768	4,333	5,426	6,232	6,888	8,990	10,066	9,863	9,655	9,859
Labor	38,052	24,522	23,893	24,141	23,453	21,870	22,654	24,935	26,274	26,953	27,823	28,716	29,774
State	2,273	2,404	2,645	2,865	2,788	3,421	3,722	3,777	4,094	4,268	4,378	4,502	4,563
Transportation	20,643	23,030	25,020	27,378	25,424	26,404	26,607	28,281	28,764	29,144	29,653	30,209	30,197
Treasury	116,368	141,009	164,892	179,231	180,253	202,386	230,571	247,239	254,978	257,687	274,544	315,139	361,880
Veterans Affairs	24,827	25,593	26,333	26,536	26,952	29,271	30,041	28,733	30,143	30,803	33,106	32,473	31,566
Environmental Protection Agency	4,312	4,076	4,490	4,867	4,904	4,871	4,906	5,492	5,824	5,726	5,573	5,444	5,197
General Services Administration	111	117	−2	380	51	−281	−463	253	47	252	339	192	76
NASA	6,853	7,055	7,251	7,403	7,591	9,092	11,036	12,026	14,137	16,413	18,148	19,379	20,122
Office of Personnel Management	21,278	22,590	23,727	23,955	26,966	29,191	29,073	33,211	33,628	34,839	37,422	39,829	42,289
Small Business Administration	661	510	680	557	−65	−54	85	1,056	280	112	207	291	361
Other Independent Agencies	11,165	11,904	9,974	12,201	14,264	23,444	32,463	26,637	23,523	16,363	16,040	14,359	13,319
Allowances									−1,070	−1,121	−1,175	−1,232	−1,293
Undistributed offsetting receipts	−51,078	−52,329	−58,656	−64,967	−72,310	−78,863	−89,155	−97,305	−112,634	−122,493	−133,712	−144,038	−156,750
(On-budget)	(−47,455)	(−46,975)	(−52,029)	(−57,780)	(−63,720)	(−67,066)	(−72,903)	(−76,114)	(−86,782)	(−91,437)	(−96,526)	(−100,006)	(−105,646)
(Off-budget)	(−3,623)	(−5,354)	(−6,627)	(−7,186)	(−8,590)	(−11,798)	(−16,252)	(−21,191)	(−25,852)	(−31,056)	(−37,186)	(−44,032)	(−51,104)
Total outlays	808,327	851,781	946,316	990,258	1,003,830	1,064,044	1,142,643	1,197,236	1,233,331	1,271,429	1,321,819	1,397,976	1,476,941

Table 5.2—BUDGET AUTHORITY BY AGENCY: 1983–1995

(in millions of dollars)

Department or other unit	1983	1984	1985	1986	1987	1988	1989	1990 estimate	1991 estimate	1992 estimate	1993 estimate	1994 estimate	1995 estimate
Legislative Branch	1,687	1,770	1,705	1,722	1,875	2,127	2,276	2,240	2,671	2,718	2,740	2,850	2,867
The Judiciary	823	904	1,052	1,044	1,267	1,338	1,476	1,734	2,075	2,278	2,345	2,409	2,469
Executive Office of the President	101	109	116	108	118	125	129	287	355	362	374	387	399
Funds Appropriated to the President	6,590	18,946	20,364	10,709	13,002	11,656	10,953	12,393	12,377	12,743	13,076	13,252	13,883
Agriculture	69,921	46,824	61,916	59,249	52,518	55,236	55,733	55,141	55,310	56,186	55,327	53,375	55,924
Commerce	1,973	2,016	2,309	1,980	2,155	2,450	2,807	3,558	2,544	2,446	2,474	2,430	2,233
Defense-Military	238,900	258,176	286,827	281,436	279,469	283,755	290,837	291,369	295,131	299,972	304,350	308,836	311,760
Defense-Civil	19,591	19,225	30,347	32,662	35,137	36,329	37,234	36,656	38,306	40,107	42,309	44,604	46,690
Education	15,397	15,423	19,077	17,872	19,608	20,234	22,956	24,111	24,618	24,217	24,374	24,526	24,664
Energy	11,893	10,953	12,618	10,559	10,125	11,163	11,697	14,296	14,761	16,880	17,568	17,784	18,832
Health and Human Services-except social security	116,833	128,000	141,107	156,535	159,715	177,043	196,638	212,349	232,642	249,273	270,679	293,501	314,269
Health and Human Services-soc. sec.	163,380	171,429	190,973	196,802	221,982	253,280	279,918	306,625	340,393	368,447	399,133	432,431	461,796
Housing and Urban Development	16,561	18,148	31,398	15,928	14,657	14,949	14,347	18,368	23,700	22,230	22,169	21,882	22,104
Interior	4,956	4,917	5,016	4,589	5,279	5,246	5,482	6,248	5,590	5,662	5,725	5,824	5,738
Justice	3,046	3,461	3,848	3,865	5,210	5,630	6,732	8,587	8,943	9,286	9,814	9,765	10,095
Labor	36,413	34,826	27,660	28,839	30,252	30,684	29,923	32,475	32,104	32,274	32,958	33,549	33,860
State	2,759	2,979	3,562	4,039	3,765	3,757	4,093	4,211	5,457	4,666	4,707	4,827	5,057
Transportation	26,308	28,586	28,770	28,079	26,122	27,168	28,455	30,177	29,336	30,349	30,674	30,734	31,294
Treasury	117,237	141,638	166,101	179,675	181,857	204,104	232,080	248,501	256,054	258,805	275,910	316,516	363,230
Veterans Affairs	25,324	26,477	27,298	27,075	27,363	29,432	29,883	29,907	30,869	31,423	31,957	32,682	33,470
Environmental Protection Agency	3,688	4,064	4,346	3,446	5,344	4,968	5,081	5,400	5,402	5,243	4,989	4,418	3,901
General Services Administration	393	247	308	287	281	184	187	119	40	51	66	66	73
NASA	7,065	7,458	7,573	7,807	10,923	9,062	10,969	12,324	15,240	17,638	19,258	20,261	20,963
Office of Personnel Management	35,724	37,685	41,686	44,280	44,775	48,141	51,248	55,602	58,197	61,301	64,454	67,965	70,757
Small Business Administration	1,278	971	1,254	714	604	418	421	928	350	471	503	542	571
Other Independent Agencies	11,368	16,998	15,561	18,497	18,789	25,908	67,501	21,321	17,835	19,636	18,617	21,488	20,020
Allowances									−1,070	−1,121	−1,175	−1,232	−1,293
Undistributed offsetting receipts	−51,078	−52,329	−58,656	−64,967	−72,310	−78,863	−89,155	−97,305	−112,634	−122,493	−133,712	−144,038	−156,750
(On-budget)	(−47,455)	(−46,975)	(−52,029)	(−57,780)	(−63,720)	(−67,066)	(−72,903)	(−76,114)	(−86,782)	(−91,437)	(−96,526)	(−100,006)	(−105,646)
(Off-budget)	(−3,623)	(−5,354)	(−6,627)	(−7,186)	(−8,590)	(−11,798)	(−16,252)	(−21,191)	(−25,852)	(−31,056)	(−37,186)	(−44,032)	(−51,104)
Total budget authority	888,082	949,921	1,074,057	1,072,773	1,099,893	1,185,526	1,309,913	1,337,621	1,396,476	1,451,149	1,522,732	1,620,926	1,718,078

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CRS Issue Brief

Space Policy

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Space Policy

SUMMARY

While the public generally thinks of NASA (the National Aeronautics and Space Administration) when discussing space activities, NASA programs are only one element of the U.S. space program. In 1958, when the space program began, responsibility for space was divided between NASA for civilian programs and the Department of Defense (DOD) for military space activities. This comparatively simple split has become much more complex over the years. Civilian weather satellites and land remote sensing satellites (the Landsat series) were transferred from NASA to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce when they became operational, since NASA is primarily a research and development agency. The Commerce Department also has an Office of Space Commerce that seeks to facilitate private sector involvement in space. The Department of Transportation is responsible for facilitating and regulating commercial launch vehicle services. Other agencies are involved in developing space policy and/or using space data (the Departments of Agriculture and Interior, for example).

The interaction among all these agencies in conducting U.S. space activities has created many policy questions, not the least of which is how to coordinate their often differing objectives. In 1988, Congress recreated the National Space Council in the Executive Office of the President, which had been abolished in 1973, in the hope of streamlining space policy coordination. The role it plays in the Bush Administration in setting space policy will be closely watched by Congress.

The budget constraints under which all agencies are operating today are intertwined with policy questions. For NASA, the space station program, with its estimated cost of $19 billion for research and development (real-year dollars), is generating the most debate. Two new initiatives in NASA's FY1991 budget request (the Human Exploration Initiative and Mission to Planet Earth) are also expected to be controversial because of their total projected costs. The most contentious DOD space issue is the development of antisatellite (ASAT) weapons.

At NOAA, the major space issue is the future of the Landsat system, which was turned over to a private sector operator in 1985. Policy disputes over promised Government subsidies have complicated the company's position and its future is in doubt. Private sector space activities generally have been extremely controversial from the standpoint of how far the Government should go to facilitate them.

ISSUE DEFINITION

The United States has a broadly based space program involving several Federal agencies, including the National Aeronautics and Space Administration (NASA) and the Departments of Defense, Commerce, and Transportation. In an era of constrained budgets, the issue of what programs should be pursued by the Government, and what space activities can and should be conducted by the private sector instead, has become highly controversial. [The Strategic Defense Initiative is a strategic defense, not a space, program and is not addressed here (see CRS Issue Briefs 88028, 88033, and 85170).]

BACKGROUND AND ANALYSIS

U.S. Civilian Space Program

In creating the National Aeronautics and Space Administration (NASA) in the National Aeronautics and Space Act of 1958 (P.L. 85-568) certain objectives were outlined, including: (1) the expansion of human knowledge, (2) the improvement of space vehicles, (3) the development and operation of space transportation systems, (4) the establishment of long-range studies of space activities for peaceful and scientific purposes, (5) the preservation of the United States as a leader in space science and technology and in their application for peaceful purposes, (6) the transfer of information to other agencies, and (7) international cooperation.

The establishment of NASA symbolized the entrance of the United States into the space age. The Soviet Union had successfully orbited the first artificial satellite, *Sputnik 1*, in October 1957, lending the U.S. space program a new urgency. The first U.S. satellite, *Explorer 1*, was orbited in January 1958. In 1961, President Kennedy announced that the United States intended to put a man on the Moon within a decade. The Apollo program, costing approximately $25 billion (then-year dollars), achieved this goal in 1969, when two astronauts landed on the Moon. Meanwhile, the 1960s witnessed the development of communications and meteorological satellites, and a wide range of spacecraft for space science missions in Earth orbit or beyond. Apollo was followed by the Skylab space station program (to which three crews were sent in 1973-1974) and the Apollo-Soyuz Test Project in which a U.S. Apollo and a Soviet Soyuz docked for 2 days of joint experiments. These successes did not provide the immediate momentum for major follow-on programs such as a permanent space station or a human mission to Mars, as some had predicted. However, in 1972 President Nixon approved NASA's space shuttle program, and in 1984 President Reagan endorsed development of a permanently occupied space station for operation in the mid-1990s.

During the 1970s and 1980s, NASA continued to launch a wide variety of space science probes. U.S. spacecraft now have visited Mercury, Venus, the Moon, Mars, Jupiter, Saturn, Uranus, and Neptune. The *Magellan* probe was launched in April 1989 to study Venus; it will reach that planet in the summer of 1990. The *Galileo* probe to Jupiter was launched in October 1989 and will arrive in 1995. Another U.S. planetary mission already under construction is *Mars Observer*, which is scheduled for launch in 1992. NASA has just initiated two new planetary exploration programs: the *Comet Rendezvous-Asteroid Flyby (CRAF)* mission, and the *Cassini* spacecraft to explore Saturn and its moon Titan.

Several astronomical observatories have been launched already, and NASA has embarked upon a "Great Observatories" program, composed of four space observatories for studies in different parts of the spectrum: Hubble Space Telescope to be launched in 1990 (for the visible wavelengths); Gamma Ray Observatory also in 1990; Advanced X-Ray Astronomy Facility in the early 1990s; and Space Infrared Telescope Facility, for which funding has not been requested yet. NASA has a wide variety of other space science satellites in development, and also will use the space shuttle and Spacelab, a laboratory that flies in the shuttle's cargo bay, for space science missions.

NASA's role in applications satellites (weather and other types of remote sensing and communications) is for R&D, not operations. When the satellites become operational, they are transferred to other Government agencies or the private sector. Some of the major applications areas in which NASA is still involved include: upper atmosphere research (including the ozone layer); developing new technology for communications satellites; and ocean sensing. NASA is proposing a program called "Mission to Planet Earth" which would use space platforms to study Earth as a system (see below).

Although NASA is the primary agency for conducting civilian space activities in the United States, other agencies are also involved. The next largest is the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce, which operates civilian weather satellites and oversees land remote-sensing satellite operations by the private sector. The Department of Transportation regulates commercial launch vehicles and the Department of Commerce is an advocate for other private sector space activities. Several other agencies are also involved in space policymaking or use of space data (for example, the Departments of Agriculture and Interior which use remote sensing data for crop forecasting and map making among other uses).

Military Space Activities

The creation of NASA was a deliberate step by the Eisenhower Administration to separate military and civilian space activities. President Eisenhower wanted to stress to the world that the United States was interested in the peaceful uses of space, but he recognized that space had military applications as well. The NASA Act specified that military space activities would be conducted under the purview of the Department of Defense (DOD).

DOD uses space for a variety of support functions -- reconnaissance (including photographic, electronic, early warning, and nuclear explosion detection), communications, weather, and navigation. In addition, DOD is interested in the possibilities of space weapons, both those that could attack enemy satellites (antisatellite weapons) and weapons based in space to attack ballistic missiles.

In 1959, the United States conducted the first test of an antisatellite (ASAT) device to destroy satellites. This capability was deemed necessary not only so that Soviet satellites could be destroyed in times of hostilities, but also because there was concern that the Soviets might place offensive weapons in orbit. Although that ASAT program did not proceed to deployment, by 1964 the United States had an operational ASAT system using ground based missiles on Johnston Island in the Pacific. The system was decommissioned in 1975, and development of a new type of ASAT device using an air-launched homing interceptor began in 1977. That system became the subject of considerable controversy in Congress and its testing was strictly limited. In early 1988, DOD announced it would terminate the program and focus instead on development of other ASAT systems. The Soviet Union developed its own ASAT system in the late 1960s, although it has not been tested since 1982. DOD considers the system operational (see CRS Issue Brief 85176).

The development of the U.S. air-launched ASAT sparked a more general debate about the "weaponization" of space that was expanded in 1983 by the announcement by President Reagan that he planned to investigate whether a strategic defense system should be developed to destroy incoming ballistic missiles, which might use space-based weapons. Called the Strategic Defense Initiative (SDI), or "Star Wars," this program has been the subject of considerable debate in Congress as well as a topic of strong international controversy. The program is still in a research phase, so it is not clear what part of it might be space-based. If the United States decides to deploy such a system, support functions of launch detection and missile tracking will almost certainly involve satellites, but whether the weapons to destroy the missiles will be based in space remains an open question. SDI is a strategic defense program, not a space program per se, and therefore is not discussed further in this issue brief (see CRS Issue Briefs 85170, 88028, and 88033).

Civilian/Military Interface

The separation between military and civilian space activities has remained in place throughout the history of the U.S. space program, but the functions performed by satellites and the vehicles that launch them are not easily divided. Both sectors use communications, navigation, weather, and remote sensing/reconnaissance satellites, which may operate at different frequencies or have different capabilities, but have similar technology. Furthermore, the same launch vehicles can be used to launch any type of military, civilian, or commercial satellite. The development of launch vehicles by NASA and DOD is now the most significant interface area between the two agencies.

The National Aeronautics and Space Act established a civilian/military liaison committee (dissolved in 1965) and the National Aeronautics and Space Council in the Executive Office of the President (abolished in 1973) to coordinate DOD and NASA programs. Coordination continued through interagency committees. President Reagan created the Senior Interagency Group/Space (SIG/Space) in 1982 to coordinate space policy, and its members included NASA, DOD, and other agencies involved in space policy, including the intelligence community. SIG/Space was in the center of many policy decisions following the shuttle accident. Its role was controversial, leading Congress to reestablish the National Space Council in 1989 (without the aeronautics function) in an attempt to streamline policymaking. The Space Council is chaired by the Vice President, and to date has been very active in issues such as the future of the Landsat system (see below), the National Aero-Space Plane program (see CRS Issue Brief 86121), and developing plans for the President's Human Exploration Initiative (see below).

Space Budgets

The majority of U.S. Government space funding goes to DOD and NASA. For FY1990, DOD estimated its space request at $18.1 billion, an 18% increase over FY1989. The actual appropriation for DOD space activities is not yet known, since there is no line item in the DOD budget for space, and DOD analysts must compute the number by assessing each DOD program and determining whether it is space-related. For the same reason, the aggregate FY1991 request for DOD space activities is not available yet.

NASA budget books show that the agency received $12.296 billion for FY1990, and is requesting $15.125 billion for FY1991, a 23% increase. OMB budget books use slightly different figures for the FY1990 appropriations ($12.323 billion) and FY1991 request ($15.239 billion), a 24% increase.

International Cooperation and Competition

The NASA Act specifically states that NASA will conduct international space activities, and since 1958, it has entered into more than 1,000 agreements with over 100 countries. One of the major cooperative projects today is the space station *Freedom*, being built by the United States, Europe, Japan, and Canada.

Cooperation between the United States and Soviet Union attracts much attention. The most notable example of cooperation was the Apollo-Soyuz Test Project in 1975, when three astronauts and two cosmonauts docked in orbit for two days of joint experiments. Cooperation is dependent on overall superpower relations, and for most of the Reagan Administration there was little of it. A new cooperative agreement, calling for data exchanges and planning coordination in space science, was signed in 1987.

The United States is also facing competition in space. The Soviet Union, Japan, China, India, Israel, and the European Space Agency (ESA) can launch satellites. ESA, comprised of 13 European countries, developed the Ariane launch vehicle, which now is being operated by a private company, Arianespace, in competition with U.S. launch vehicles. China also has begun to have success in marketing its launch vehicles worldwide. Even the Soviet Union has become interested in the commercial prospects of launch vehicles, selling remote sensing data, and flying materials processing experiments for other countries. Other areas of competition include: France in remote sensing, Europe and Japan in communications satellite technology, future generation launch vehicles, and microgravity materials processing. (CRS Report 89-183 SPR, *Space Activities of the United States, Soviet Union, and Other*

Launching Countries/Organizations, 1957-1988, provides an overview of these programs.)

Space Program Issues

There are many issues facing the U.S. space program today, and the following list briefly summarizes those likely to be of most concern in the 101st Congress. More detailed CRS products are available on many of these issues.

Trips to the Moon and Mars: The Human Exploration Initiative

On July 20, 1989, the 20th anniversary of the first Apollo landing on the Moon, President Bush made a major space policy address endorsing the goal of returning humans to the Moon and then going on to Mars "in the 21st Century." While the President's speech provided concrete goals for the space program, some Members of Congress criticized it for not having a specific timetable or cost estimates. The President assigned the task of developing a schedule and budget to the National Space Council.

The Space Council continues to review options for meeting the President's goal, now named the "Human Exploration Initiative." The HEI is not identified as a specific line item in NASA's FY1991 budget request, but OMB has identified $1.3 billion that is related to the HEI. Most of the funding is for programs that have been underway for some time (such as the development of space nuclear power, an Advanced Launch System and the National Aero-Space Plane, and "mission studies" to determine the best approach to getting to the Moon and Mars). OMB budget books show $859 million being spent on the programs in FY1990; thus the new budget would be a 47% increase.

The HEI is controversial for several reasons. First, it is expected to be extremely expensive over the long term. Although neither NASA nor the Space Council has provided any cost figures for the total program, OMB director Darman has stated that it would cost $400 billion over 30 years. Without a timetable for the program, it cannot be determined when and by how much NASA's budget would have to grow. Second, critics of the HEI argue that human exploration of the solar system is unnecessary, and too risky, preferring robotic spacecraft for such activities. The rationale for human exploration of the solar system was addressed in the 1986 report of the U.S. National Commission on Space, entitled *Pioneering the Space Frontier*. The Commission was established by Congress and its members appointed by President Reagan. Some view President Bush's initiative as an endorsement of the Commission's findings. Advocates of the HEI point to the large segment of the world's population that has been captivated for decades by the concept of sending humans to Mars. In fact, many assume that human expeditions to Mars will be international, including at least the United States, Europe, Japan, Canada (the participants in the Space Station *Freedom* program) and the Soviet Union. Thus, they see the HEI as a natural evolution of space activities and the human desire to explore new frontiers.

A third aspect of the controversy is whether humans should return to the Moon before going to Mars. Some argue that valuable activities could be performed on the Moon (such as establishing an astronomical observatory on the far side of the Moon where it would be shielded from the radio and light interference from Earth) and it could serve as a testing ground for systems and procedures to be used in exploring Mars. Others argue that the Moon and Mars are sufficiently different that little or no useful information will result from a lunar base, and establishment of a lunar observatory has a lower priority than human exploration of Mars. The current plans for the HEI call for a return to the Moon before going on to Mars, however.

Mission to Planet Earth

Another program President Bush endorsed in July 1989 is Mission to Planet Earth (MPE), which will provide data to help scientists better understand the Earth as a total system and what effect the human population has on the planet. Generically, this field of study, called "Global Change research," includes such topics such as global warming, ozone depletion, and deforestation. The United States is working with the international scientific community to study global change. The scientific program is being developed through the National Academy of Sciences, and the Government agency programs needed to accomplish the scientific goals are coordinated through the Committee on Earth Sciences in the White House Office of Science and Technology Policy. NASA is one of seven agencies working on global change through CES (the others are the National Science Foundation, Environmental Protection Agency, and Departments of Commerce, Interior, Agriculture, and Energy, and some add Defense to the list.

There are several different definitions of MPE, but NASA defines it as certain satellites and associated data systems needed to provide data for the Global Change Research Program. Ultimately, NASA plans to have four large, multipurpose spacecraft called "platforms" in polar orbit (around Earth's poles), five platforms in geostationary orbit (35,800 kilometers above the Equator, where a satellite maintains a fixed position relative to any point on Earth), plus a variety of other satellites in different orbits from which special observations can be made (called "Earth Probes"). The geostationary platforms are not part of the current NASA budget request. Thus, NASA now defines MPE as the polar platforms (called the "Earth Observing System"), the Earth Probes, and associated data systems. NASA plans to provide two polar platforms, with the third from Europe, and the fourth from Japan.

Using NASA's definition, $268 million is included in the FY1991 NASA budget request for MPE: $103 million for Earth Observing System (EOS) sensors and data systems; $132 million for development of the EOS platform itself; $25 million for Earth Probes; and $8 million for construction of a facility at NASA's Goddard Space Flight Center to house the EOS Data Information System (EOSDIS). There is other funding in the NASA budget and elsewhere in the U.S. Government for the Global Change Research Program (a total of $1 billion Government-wide).

The NASA program for MPE may generate controversy, however, for several reasons. First is the expected cost of the program, which NASA estimates at $20-30 billion (FY1990 dollars) over 20 years. This estimate does not include the geostationary platforms, a special instrument NASA hopes to fly on a polar platform (a synthetic aperture radar), or work by other U.S. agencies or other countries.

Approximately 40% of NASA's cost is for the spacecraft, 40% for the data system, and 20% for the scientists and computer programmers. The data system will be massive and complex, since the EOS platforms alone will transmit an amount of information equivalent to the contents of the Library of Congress every day.

Second, although many people want quick answers to questions about global change, scientists feel that they need a 15-year data set before they can answer many basic questions, and it will take 5-10 years to build the systems to get that data set. Whether MPE and the Global Change Research Program in general can sustain political and financial support over two decades is uncertain.

Third, some scientists question NASA's approach to MPE. The platform is one in which a single structure houses a large array of sensors. Originally, this design was expected to lead to cost efficiency by having many sensors share the same subsystems (electrical power, communications, etc.). Platforms in polar orbit would have been serviced by astronauts in the space shuttle, so there were few concerns about the impact of a subsystem failure (a short circuit, for example). Following the space shuttle *Challenger* tragedy in 1986, however, objectives for utilization of the shuttle changed, and plans to fly the shuttle in polar orbits were dropped, so the platforms will not be serviceable by astronauts. Hence, scientists have become concerned about the "all your eggs in one basket" approach of the platform concept today. The polar platforms also were to have been launched by the shuttle; now they will be launched by a Titan IV rocket. The Titan family of rockets has very good reliability, but not as high as the shuttle. Some observers have therefore expressed concern about the possibility of losing the platform because of a launch failure.

NASA insists that the platform concept is still the best because the sensors on the platform will be able to view the same event at the same time (called simultaneity). If they were separated onto several spacecraft, the sensors might see events several minutes (or hours) apart, complicating analysis of the data. Critics of NASA's approach agree that *some* of the sensors planned for the platforms need to view the events simultaneously, but not all. They feel the sensors could be separated into smaller groupings without a significant impact on the usefulness of the data. NASA also feels that the risk of launch failure is not great, and that since there will be other platforms under construction (the agency plans to build a total of six platforms so two are operating at any one time throughout the life of the program), if one were lost, the amount of time needed to get a replacement into orbit would be acceptable.

Space Station

The space station program is discussed in more detail in CRS Issue Brief 85209, *Space Stations*. In brief, President Reagan directed NASA to build a space station capable of being permanently occupied. The space station will be an international laboratory where research can be conducted in fields such as microgravity materials processing and life sciences. NASA also sees it as a stepping stone to further exploration of the solar system. Originally planned for operation in 1994, the space station is now expected to be operational in mid-1997, following several schedule slips caused by budgetary constraints. NASA currently estimates that the first phase of the space station program will cost $19 billion (real year dollars assuming approximately 5% inflation through 1996). A second phase, not yet approved, would cost $4.4 billion (FY1988 dollars). Another $7 billion (FY1988 dollars) is expected to be spent by Japan, Canada, and the European Space Agency for their contributions to space station hardware. The space station will include one central structure and separate platforms located near the station or in polar orbit.

The most controversial aspect of the space station program is its cost and what impact space station spending might have on other NASA programs. More broadly, some observers question whether the Nation can afford the space station at a time when there are increased calls for more attention to problems such as the homeless and environmental issues. In the fall of 1989, budget pressures forced NASA to stretch out construction of the first phase of the station over almost 2 more years. (Although it will be permanently occupied beginning in 1997, assembly will not be complete until 1999.) This action created concern for the international partners, especially ESA and Japan which are building two of the three laboratory modules, since the delay would significantly affect when their modules would be launched.

Launch Vehicles

Issues surrounding launch vehicles are discussed in more detail in CRS Issue Brief 86121, *Space Launch Options*. The matter of how best to provide access to space became prominent after a series of launch failures in 1986, compounded by a limited availability of various launch vehicles, created a severe shortage in capability to launch U.S. satellites. The United States has four ELVs -- Scout, Delta, Atlas, and Titan -- and one reusable system -- the space shuttle. When the shuttle program was approved in 1972, it was with the intent that it would replace all the ELVs except Scout. Although the Government stopped ordering Atlas and Delta vehicles as planned, in 1984 the Air Force decided to retain the Titan family of vehicles and to add a new member (Titan IV).

The space shuttle *Challenger* tragedy in January 1986 not only took the lives of seven astronauts, but grounded one of the major U.S. launch vehicles. Launch failures also temporarily grounded the Titan, Delta, and Atlas vehicles, severely complicating plans to launch satellites. Consequently, the Government adopted a "mixed fleet" approach that will use the shuttle *and* ELVs. DOD is procuring new versions of Atlas and Delta, while it and NASA are contemplating what new vehicles may be needed.

Several U.S. private companies are marketing launch vehicles for commercial launches, in competition with Europe's *Ariane*, China's *Long March*, and a variety of Soviet rockets. A major issue is how far the Government should go to facilitate the success of the U.S. companies.

Commercialization of Space

Through language in the FY1985 NASA authorization bill, Congress amended the National Aeronautics and Space Act requiring NASA to encourage "the fullest commercial use of space." In 1984, NASA established its Office of Commercial Programs, following a Presidential policy statement (see below). In February 1988 the White House released 15 commercial space initiatives, including support for several specific private projects.

Communications satellites are often cited as the first commercial space activity. NASA and the private sector are now pursuing commercial activities in materials processing, launch vehicle services, and on-orbit services. Materials processing is based on the ability to produce purer substances or new materials in microgravity, on space facilities such as the space station. (Launch vehicle services are discussed above.) Private companies also see a future market for on-orbit services, delivering fuel or supplies or providing space modules in addition to those proposed by NASA.

Of the many questions about space commercialization, the primary issue is how realistic expectations are that the private sector will have a major role in space in the near future. Efforts to turn Government space programs over to the private sector ("privatization" of space) do not have a good track record (see the Landsat issue described below, for example); neither do those for space "commercialization" where the private sector comes forward with a new idea.

Landsat

This issue is discussed in CRS Report 89-242 SPR, *The Future of the Land Remote Sensing Satellite System (Landsat)*. Since 1972, the United States has launched a series of remote sensing satellites called "Landsat" for monitoring the Earth's surface. Landsat data are used for crop forecasting, mineral exploration, land use management, and similar activities. Developed by NASA, the Landsat system was turned over to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce in 1979, with the expectation that it would be transferred to the private sector after 10 years. Plans to turn operations over to the private sector were accelerated by the Reagan Administration, and in 1984 Congress passed the Land Remote Sensing Commercialization Act to provide for private operation of the system.

In 1985, a contractor named EOSAT was selected to operate the two existing Landsat satellites and to build and launch two more. The Reagan Administration promised EOSAT $250 million over several years to facilitate the transfer. A tug of war ensued between the Administration and Congress over upholding that commitment. By the beginning of 1988, the agreement between EOSAT and the Government had been modified so that EOSAT would only have to build one more satellite (instead of two) and the Government subsidy was reduced to $209 million. The satellite, *Landsat 6*, is expected to be launched in 1991.

NOAA, which manages the EOSAT contract, had not assumed that the two existing satellites (*Landsat 4* and *5*) would still be operating in 1988, however, and was not prepared to fund their operations. The contract with EOSAT states that the company will operate those two satellites under contract to NOAA, and for FY1989 the Congress added $9.5 million to NOAA's budget to operate the satellites for the first 6 months of the fiscal year. NOAA was directed to find some way to fund operations for the remainder of fiscal year, but in early 1989 NOAA stated that it did not have any money available, and would direct EOSAT to turn off the satellites at the end of March. This sparked considerable concern in the executive branch and Congress. Vice President Quayle, in his role as chairman of the National Space Council, succeeded in getting agreement from other Government agencies to provide money to NOAA to continue operations through the end of the fiscal year. The

Council also recommended that the Government continue to support Landsat operations in the future.

Although the Administration submitted a budget amendment calling for $19 million for Landsat operations in FY1990, it was after Congress had already begun action on the relevant funding bills. Consequently, Congress provided only $9.5 million, placing the system in a situation similar to that in FY1989. Where the additional money will come from for operations in FY1990 has not been specified, but probably will be obtained the same way as in FY1989 -- contributions from agencies that use Landsat data.

Finding a permanent home for Landsat continues to be an issue. The Space Council is considering whether to leave the program under NOAA's aegis, or transfer it to the Department of Defense (a major user of the data). Some Members of Congress have expressed concern about turning the system over to DOD, which they fear could result in data being less available to domestic and international civilian users. Some question the need to move the program out of NOAA, and others feel that if the program is moved, it should go back to NASA.

Antisatellite (ASAT) Weapons

This issue is discussed in more detail in CRS Issue Brief 85176, *ASATs: Antisatellite Weapon Systems*. In brief, the controversy involves whether the United States should develop weapons to destroy enemy satellites. The United States had a ground-based ASAT system from 1964-1975, and began development of an air-launched system in 1977. Congress opposed testing the ASAT system against objects in space because of concerns that it would destabilize relations with the Soviet Union. Advocates of the system argue that the Soviets have an operational ASAT system of their own (although it has not been tested since 1982). DOD cancelled the air-launched ASAT program in early 1988 because of the continued congressional bans on testing, and began looking at alternatives. In the FY1990 budget request, DOD is proposing a broad ASAT program involving the Army, Navy, and Air Force. The new DOD program has stimulated continued congressional debate on the need for a U.S. ASAT system, and whether an agreement limiting ASATs should be negotiated with the Soviet Union.

CONGRESSIONAL HEARINGS, REPORTS, AND DOCUMENTS

U.S. Congress. House. Committee on Science and Technology. Committee on Armed Services. Assured access to space during the 1990s. Hearings, 99th Congress, 1st session. July 23-25, 1986. Washington, U.S. Govt. Print. Off., 1986. 183p. (Also report, January 1986, 29p.)

U.S. Congress. House. Committee on Science and Technology. United States civilian space programs. v.1 and 2. Prepared by the Congressional Research Service, U.S. Library of Congress. Washington, U.S. Govt. Print. Off., 1981 (v.1, 1339p.) and 1983 (v.2, 381p.).

At head of title: 97th Congress, 1st session (v. 1); 98th Congress, 1st session (v.2). Committee prints.

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Soviet space programs: 1981-1987. Parts 1-2. Prepared by the Congressional Research Service, U.S. Library of Congress. Washington, U.S. Govt. Print. Off., 1988.

CHRONOLOGY

07/20/89 --- In the recognition of the 20th anniversary of the first Apollo landing on the Moon, President Bush made a major space policy address setting out long-term goals, including returning humans to the Moon and going on to Mars "in the 21st Century."

04/20/89 --- President Bush signed an executive order formally establishing the National Space Council.

03/01/89 --- As required by the FY1989 NASA authorization bill, President Bush announced the membership and goals of the National Space Council.

02/11/88 --- President Reagan announced a new U.S. space policy, consolidating and clarifying previous policy directives.

07/22/86 --- National Commission on Space submitted its report on long-term goals for the U.S. civilian space program to the President and Congress.

01/28/86 --- Space shuttle *Challenger* exploded 73 seconds after lift-off, killing all 7 crew members.

01/25/84 --- In his State of the Union address, President Reagan called for the development of a permanently occupied space station within a decade.

04/12/81 --- First launch of the space shuttle.

07/20/69 --- First men landed on the Moon (*Apollo 11*), fulfilling President Kennedy's 1961 mandate.

05/25/61 --- President Kennedy called upon the Nation to commit to the goal of landing a man on the Moon by the end of the decade.

05/05/61 --- Alan Shepard became the first American to reach space, although his flight was suborbital.

04/12/61 --- Yuri Gagarin became the first human to orbit Earth.

10/01/58 --- National Aeronautics and Space Administration was created.

01/31/58 --- First U.S. Satellite, *Explorer 1*, was launched.

10/04/57 --- World's first satellite, *Sputnik 1*, was launched by the Soviet Union.

THE NATIONAL SPACE COUNCIL

INTRODUCTION

The FY89 NASA Authorization bill, signed into law by President Reagan in November 1988, created the National Space Council. On April 20, 1989, President Bush issued an executive order which officially established the council. The National Space Council is largely modeled on the old National Aeronautics and Space Council which was created in the National Aeronautics and Space Act of 1958, with some modifications. The most obvious modification is that the current council does not include aeronautics, as the original NASC did. Other differences, such as the number of council members and the atmosphere in which it is operating, may affect what the National Space Council can accomplish.

Congress created the Space Council based on the belief that it would be a better mechanism for making space policy than the Senior Interagency Group on Space (SIG-Space). It was not Congress's first attempt to replace SIG-Space. President Reagan vetoed the FY87 NASA authorization bill in part because he opposed the Space Council. Congress and President Bush agreed on the need for the Space Council, but both have left the Space Council a lot of leeway in its operations.

Vice President Quayle, as Chairman of the Space Council, has already intervened in at least two space policy decisions (Landsat and National Aero-Space Plane). The council has begun review of other space issues. Observers have called for the Space Council to achieve a wide range of goals. It may not be desirable or even feasible for the National Space Council to try to accomplish all of them.

This paper will: review the history of the National Aeronautics and Space Council; outline and discuss the reasons for the creation of the National Space Council; and discuss the current accomplishments, possible roles, and prospects of the new council.

HISTORY OF THE NATIONAL AERONAUTICS AND SPACE COUNCIL

The National Aeronautics and Space Act of 1958 (NAS Act) established the National Aeronautics and Space Administration (NASA) as the civilian space agency, with military space activities assigned to the Department of Defense. The Act created the National Aeronautics and Space Council (NASC) to develop and coordinate national space policy between these agencies. The Council was originally chaired by the President and included the Secretary of Defense, Secretary of State, NASA Administrator, and Chairman of the Atomic Energy Commission. In addition, the President could appoint one more Government representative and three individuals from the private sector. The statutory duties of the NASC included surveying and developing a comprehensive plan for U.S. aeronautical and space activities. The NASC was also responsible for designating which agency would direct

Reproduced from The National Space Council, by Patricia E. Humphlett.
Washington, Congressional Research Service, 1989. 13 p.
(CRS Report to Congress 89-429 SPR)

major programs, coordinating activities, and resolving any disagreements between agencies.

Congress initiated the creation of the council because it believed that there was a great need for coordination of space policy between the agencies involved in space. The Senate Special Committee on Space and Astronautics was concerned with possible overlap between government agencies, cooperation between agencies, and who would have general direction over space policy. The council was set up in order to centralize responsibility for resolving problems, provide continuity and consistency of advice, and coordinate and resolve conflicting views or programs between Government agencies.[1] According to one of the drafters of the original legislation, the purpose of the NASC was "behind the scenes" coordination, not announcing major new initiatives.[2]

President Eisenhower initially resisted the creation of the NASC and, not surprisingly, made little use of it.[3] NASA officials, including Administrator Glennan, preferred direct negotiations with other agencies and with the President rather going through the NASC.[4] President Eisenhower's Science Advisor, James Killian observed that it was extremely difficult to convene a meeting of such high ranking officials who were busy with other issues and meetings, and noted that President Eisenhower presided over the NASC only a few times.[5]

During the Eisenhower Administration, Congress's first encounter with the NASC was not very productive. In 1959, NASA Administrator Glennan testified before the Senate Space Committee's Subcommittee on Governmental Organization for Space Activities and, when asked about NASC activities, declined to answer because NASC discussions were "confidential in nature as confidential advice given to the President." When pressed further, Mr. Glennan promised to consult with the President, but later informed Congress that no further information on NASC deliberations would be forthcoming.[6]

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[1] U.S. Congress. Senate. Final Report of the Special Committee on Space and Astronautics, 86th Cong., 1st Sess., Rept. No. 100, 1959. p. 5-8.

[2] Telephone conversation with Eilene Galloway, June 26, 1989.

[3] Rosholt, Robert L. An Administrative History of NASA, 1958-1963, NASA, 1966. p. 13

[4] Logsdon, John M. The Decision to Go to the Moon. MIT Press, Cambridge, 1970. p. 70.

[5] Killian, James R. Sputnik. Scientists, and Eisenhower, MIT Press, 1982. p. 138.

[6] Rosholt, p. 98-99.

President Kennedy used the NASC much more actively than did President Eisenhower. In addition, he made several changes to its structure. He eliminated the four appointed members and made the Vice President (instead of the President) Chairman. Including the Vice President, the NASC then had five members. As Vice President, Lyndon Johnson became Chairman of the NASC. While in the Senate, Vice President Johnson had been an ardent supporter of the space program and was instrumental in the creation of the NASC. President Kennedy named Dr. Edward C. Welsh as Executive Secretary. Dr. Welsh had previously served on the staff of Senator Symington, who chaired the Senate Space Committee's Subcommittee on Governmental Organization for Space Activities.[7] The staff, which was limited by the NAS Act to three persons, were engineers and scientists from the private sector.[8]

President Kennedy directed the NASC to review the national space program and to make recommendations as to how the United States could compete with the Soviet Union in space. Vice President Johnson and Dr. Welsh conducted a series of meetings with individuals from the Government and the private sector which assessed where the United States stood in space and how it should proceed, specifically regarding putting a man on the moon, as well as other space programs. They reported back to President Kennedy two weeks later with specific recommendations, which provided the basis for Presient Kennedy's major space initiatives.[9] During 1961, the NASC dealt with issues and policy decisions including: the need for an accelerated large booster program resulting in a supplemental request for funding; the decision to send a man to the moon within the decade; the President's communication satellite policy, issued in July 1961; writing the Administration's draft legislation, submitted to Congress, which ultimately became the Communications Satellite Act of 1962; and coordinating a decision to allow a nuclear reactor on a military satellite.[10]

Vice President Johnson's personal interest and commitment to the space program played an important part in the NASC's achievements. Vice President Johnson gave the NASC the active role that he had advocated for it while in the Senate. James Killian, Special Assistant to President Eisenhower for Science and Technology, commented that "Perhaps it might be more accurate to say that the Vice President was a space council all in himself."[11]

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[7] Rosholt, p. 189-190.

[8] Telephone conversation with Burt Edelson, NASC staff member 1962-1965, July 6, 1989.

[9] Logsdon, p. 109-119.

[10] Report to the Congress from the President of the United States, United States Aeronautics and Space Activities, 1961. p. 5.

According to Burt Edelson, a NASC staff member from 1962 to 1965, the NASC was initially successful both because Vice President Johnson was a strong individual and was personally interested in the space program, and also because there were many important decisions that needed to be made in the space program in 1961. However, during the following years, the NASC was involved in more secondary, bureaucratic decisions.[12] Although the NASC may have continued to perform a useful function, it was not as visible.

During the Johnson Administration, Vice President Hubert Humphrey served as chairman of the NASC, and it continued to serve an important role as a mechanism for coordination and advice. In 1969, Vice President Spiro Agnew served as Chairman and William Anders (a former astronaut) became Executive Secretary. However, President Nixon used the NASC very little, reportedly preferring to consult with his own aides,[13] and abolished it in 1973. During the Carter Administration, space policy was developed and coordinated in a Policy Review Committee on Space which was chaired by the Director of the Office of Science and Technology Policy (OSTP), Frank Press, but operated under the auspices of the National Security Council. The Committee completed a general review of the space program and then met as needed to address issues that demanded its attention. The Committee included representatives from all of the agencies involved in space policy,[14] and was responsible for developing several major space policy directives during the Carter Administration.

WHY DID CONGRESS CREATE THE NATIONAL SPACE COUNCIL?

Under the Reagan Administration, the Senior Interagency Group on Space (SIG-Space) was the interagency forum for developing and coordinating space policy. President Reagan created SIG-Space in his first space policy review.[15] It was chaired by the National Security Advisor and included representatives from: the Departments of Defense, State, and Commerce; the Director of Central Intelligence; the Arms Control and Disarmament Agency; the Joint Chiefs of Staff, NASA, the Office of Management and Budget; and the Office of Science and Technology Policy. SIG-Space reviewed and produced statements on space policy generally, and also met to discuss problems or conflicts between agencies. The group then conveyed its recommendations on how to deal with the issue to the President through the National Security Council.

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[11] Killian, p. 138.

[12] Edelson, op. cit.

[13] Hirsch, R. and J. J. Trento. The National Aeronautics and Space Administration. New York, Praeger, 1973. p. 139.

[14] The following agencies participated in the 1978 space policy review: NASA, the Depts. of Commerce, Defense, Interior, Agriculture, Energy, State, the National Science Foundation, Agency for International Development, the Director of Central Intelligence, the Joint Chiefs of Staff, the Arms Control and Disarmament Agency, the White Domestic Policy Staff, the National Security Council and the Office of Management and Budget.

Many members of the space community criticized SIG-Space. Some argued that SIG-Space conducted its policy debates and discussions with too much secrecy and that there was not enough public or congressional access to policy debates and decisions. Another criticism was that the decision-making process was far too slow, especially in the weeks and months following the January 1986 space shuttle Challenger accident. Some believed that SIG-Space was slow in dealing with civilian space issues because the National Security Council was preoccupied with national security issues. Others argued that too many Government agencies were involved in deciding civilian space policy, an area that they felt NASA should dominate. Some claimed that high ranking officials rarely attended SIG-Space meetings and instead sent lower level officials who did not have authority to negotiate or commit to decisions.

In addition to SIG-Space, under the Reagan Administration, the Economic Policy Council (EPC) also became involved in developing commercial space policy. According to critics, this elevated the role of the Department of Commerce in space policy and further complicated an already burdensome space policy decision-making process. The EPC developed a series of commercial space initiatives that were released in early 1988, simultaneously with a new Reagan space policy, the last of his Administration.

Out of the criticism of SIG-Space emerged the idea to recreate the NASC, without the aeronautics component, but otherwise returning to a mechanism created in the original NAS Act of 1958. In 1986, the National Commission on Space released its report describing its vision for the U.S. space program for the next 50 years. The commission recommended that the President re-establish the National Aeronautics and Space Council in order to provide for interagency coordination and to generally oversee the U.S. space program.[16] Congress included language creating the National Space Council in the FY87 NASA Authorization, but the President vetoed the bill, primarily because of its inclusion.

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[15] White House Fact Sheet, National Space Strategy (Aug. 15, 1984). Aeronautics and Space Report of the President, 1984 Activities, p. 137-39.

[16] National Commission on Space. Pioneering the Space Frontier. New York, Bantam Books, 1986. p. 155.

ROLE OF THE NATIONAL SPACE COUNCIL

Title V of the FY89 NASA Authorization Act (P.L. 100-685) created the council, but included only a brief description of its composition or purpose, leaving such matters to the discretion of the President. Reportedly, President Reagan had vetoed the FY87 bill because it was so specific in the council's membership and purpose that it gave the Executive little latitude in its creation. Therefore, to avoid veto, Congress deleted the specific language from the FY89 bill. P.L. 100-685 states only that the council was to be chaired by the Vice President and headed by a civilian executive secretary who directs a staff of no more than seven people. In addition, P.L. 100-685 required the President to submit a report to Congress outlining the composition and functions of the Space Council. Bush submitted the report on March 1, 1989, as directed.[17] On April 20, 1989, President Bush issued an executive order which formally established the Council.[18]

The National Space Council members are: the Secretaries of State, Defense, Commerce, Transportation, and Treasury; the Director of the Office of Management and Budget; the Chief of Staff to the President; the Assistant to the President for National Security Affairs; the Director of Central Intelligence; the Assistant to the President for Science and Technology; and the NASA Administrator.[19] Eleven agencies or offices are represented in addition to the Vice President, making it much larger than the NASC and very similar in size to SIG-Space. The March 1 report listed only nine agencies. The Science Advisor and the Secretary of Treasury were not added until the executive order was issued in April.

According to the April 20 executive order, the functions of the Space Council are: 1) advise and assist the President, 2) review U.S. space policy and develop recommendations for the President, 3) monitor and coordinate the implementation of the President's space policy, and 4) foster cooperation and information exchange between all sectors of the U.S. space program. President Bush directed the Space Council to submit to him an annual report including its recommendations for U.S. space policy.

The Space Council is establishing working groups made up of the council members. Each working group will be comprised of a smaller number of members on a particular subject to facilitate more frequent meetings. It is likely that each council member will designate a lower level official to the working group. The working groups will produce option papers and recommendations that will be presented to the full Space Council. Thus, the National Space Council will meet primarily to reach final decisions on policy recommendations to forward to the President. The executive order also provided that the Vice President establish a space policy advisory board comprised of private citizens. The Vice President plans to appoint members of the advisory board later this summer, and reportedly will name a large number of members to ensure wide representation.[20]

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[17] Composition and Functions of the National Space Council--Message from the President received during recess-- PM 24, Congressional Record. Mar. 2, 1989. p. S1997.

[18] Executive Order 12675. Federal Register, v. 54, no. 78, Apr. 25, 1989. p. 17691.

[19] The Executive order lists NASA last, following the other agencies, which some observers felt was a slight against NASA.

Mark Albrecht, formerly on Senator Pete Wilson's staff, is Executive Secretary of the National Space Council. Because the Space Council has limited funding $181,000 for March through September FY89, most of its staff is detailed from other agencies. The NASC's staff members were permanent employees which gave the council the advantage of longer-term commitment from its staff and therefore greater consistency of advice and better institutional memory. In addition, permanent staff have greater allegiance to the White House and its national outlook than temporary or rotating detailees who are still technically employees of specific agencies.

WHAT HAS IT ACCOMPLISHED THUS FAR?

Although the National Space Council was only recently created, it has already stepped into the limelight. In early March 1989, Vice President Quayle interceded when the Department of Commerce ordered two Landsat satellites to be turned off at the end of March. The Reagan Administration had not requested funding for their continued operation in the FY89 budget and Congress had added only partial funding. Vice President Quayle's action continued the operation of the satellites through early summer pending a National Space Council review of remote sensing policy. Reportedly, the Landsat decision was made at a National Space Council meeting attended by representatives of many of the agencies.[21] In May 1989, the National Space Council unanimously recommended that the Federal Government make a long-term commitment to Landsat, which would include follow-on satellites after the one satellite, Landsat 6, that is currently under construction.[22]

The National Space Council recently addressed the issues surrounding the National Aero-Space Plane (NASP), including whether and how to continue the project. The Department of Defense cut $200 million for NASP from the FY90 budget, leaving $100 million in funding which it planned to transfer to

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[20] Defense Daily, June 7, 1989, p. 376.

[21] Foley, Theresa M. White House Reverses Order To Halt Landsat Operations, Aviation Week and Space Technology, Mar. 13, 1989. p. 30. See also, Rohrer Karl A. and Marcia S. Smith. The Future of the Lands Remote Sensing Satellite System (Landsat). CRS Report 89-242, Apr. 13, 1989.

[22] Aerospace Daily, May 15, 1989, p. 258.

NASA, with the expectation that NASA would continue the program without DOD funding in the future. The Space Council conducted a review of the NASP program and recently met to consider recommendations for its future.[23] The Council recommended to the President that the program be scaled back and proceed more slowly than planned by the Reagan Administration, but gave the program much more support than in the Bush budget request.[24]

WHAT IS EXPECTED OF THE NATIONAL SPACE COUNCIL?

The National Space Council comes up frequently in discussions about policy choices and funding battles in the U.S. civilian space program. The name of the Space Council is invoked so frequently as the answer to civilian space program dilemmas that it may be in danger of being overburdened with expectations.

The National Space Council could serve, or be expected to serve, the following roles with regard to the U.S. civilian space program:

Interagency Coordination and Policy Oversight

Perhaps the most frequent description of the role of the National Space Council is that it will coordinate policy among agencies. In recent years, agency disagreements have primarily focused on conflicting priorities among programs, especially resulting from limited funding resources. Funding battles are expected to continue in the next few years. The council will probably face similar dilemmas. For example, the Department of Commerce would not have cut off Landsat operations nor would the Department of Defense have stopped funding NASP if there had been unlimited funding available for those programs. The program changes were made in the face of competing priorities and the need to make funding cuts somewhere. Other agencies are reluctant to contribute funding from their own programs. NASA may face a funding shortfall that could force a decision whether or not to go ahead with the space station Freedom. The question then is whether, in this budget climate, there are any policy decisions that are not funding decisions. For those policy decisions that are based on funding, it is unclear how much the Space Council can do to get funding either from other agencies or from Congress.

In June 1989, Representative Packard introduced H.R. 2674 to promote the U.S. commercial launch industry. The bill would require both NASA and the Department of Defense to launch all payloads on U.S. commercial launch vehicles unless the National Space Council certified that they had an overriding need to use Government launch vehicles. Given NASA's investment and planned future use of the space shuttle and DOD's strong preference to maintain control of its payloads by using military launch vehicles, should this legislation be enacted, the National Space Council would find itself in the middle of a dispute between NASA, DOD, the commercial launch industry, and the Department of Transportation, to the extent that it promotes the commercial launch industry.

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[23] Covault, Craig. Bush Administration Speeds NASP Review. Aviation Week and Space Technology, June 5, 1989. p. 24-25.

[24] Aerospace Daily, July 5, 1989, p. 4.

Increase the Visibility of the Civilian Space Program

Many observers expect that the National Space Council will raise the visibility of the space program, presumably bringing space policy issues to the President's attention. As noted under the history of the NASC, the individuals involved and the national importance of the program have more influence on the space program's visibility than the location of the group coordinating policy. The Space Council can benefit from the Vice President's active involvement and the Council's initial success. However, increased visibility does not guarantee that all problems will be solved, and may, in fact, draw more divergent opinions into the debate.

Inform and Involve Congress in Executive Branch Policy Decisions

Congress was frustrated with the secrecy of SIG-Space and created the National Space Council to increase congressional involvement. There have already been some favorable reports from Congress that the Space Council is willing to inform Congress.[25] However, what NASA Administrator Glennan told Congress in 1959 is still true today. As part of the Executive Office of the President, the Space Council can claim executive privilege concerning Council deliberations. Furthermore, because the Executive Secretary is not confirmed by the Senate, he can not be called to testify before Congress. Thus, it is still feasible that the Space Council could debate and recommend policy in secrecy. Thus far, the Space Council, mindful of one of the reasons it was created, has made an effort to keep communications open with Congress. Congress will remain vigilant as to the Space Council's openness. Although the Council now seems willing to inform Congress, it is unknown whether in the future it will solicit and take into consideration the congressional viewpoint on space policy issues before making a recommendation to the President. That function may or may not be the Council's role.

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[25] New Technology Week, Feb. 13, 1989, p. 8; and Aerospace Daily, Apr. 17, 1989, p. 84.

Review and Study the U.S. Civilian Space Program

The Executive order creating the National Space Council states that it will review U.S. space policy and provide recommendations to the President. The Reagan Administration oversaw a number of studies on long-range goals, remote sensing, commercial space, and other issues and some believe that further studies are not necessary and instead would prefer to see more concrete action.[26] The Space Council reportedly expects to have a short-term policy review completed by the end of the summer. That review will focus on implementation and will not result in major changes to Reagan Administration space policy.[27]

Provide a Liaison with Industry on Space Commercialization

The NASA Commercial Programs Advisory Panel recently called for the creation of a permanent industry advisory panel to advise both the National Space Council and NASA and to create long-term goals in commercial space.[28] The NASA panel's recommendation would place greater NASA and National Space Council control over commercial space programs. Under the Reagan Administration, the Department of Commerce and Economic Policy Council (EPC) were very active in commercial space policy. The EPC is still in existence, but has not recently been active in space policy. The Space Council plans to appoint an advisory group that will include the commercial space industry, but has not yet indicated that commercial space is a priority in the near term. The industry advisory group will provide a forum for the commercial space industry to express its opinions. However, the question remains whether the commercial space industry requires merely policy statements in support of its efforts or increased funding or other Government involvement to further its development.

Guarantee Policy Continuity and Stability

The Commerce Department's Commercial Space Advisory Group issued a report in January 1989 that emphasized that a stable national space policy combined with increased funding are critical to the success of commercial space endeavors.[29] Former NASA Administrator and current chairman of the board of Spacehab, James Beggs, stated that he thought that the Space

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[26] Foley, Theresa M. Quayle Denounces U.S. Reliance on Foreign Space Launch Vehicles. Aviation Week and Space Technology, Apr. 10, 1989. p. 21.

[27] Defense Daily, June 7, 1989, p. 376.

[28] Defense Daily, May 26, 1989, p. 321.

[29] Foley, Theresa. Commercial Space Shows Long-Term Promise Despite Early Setbacks. Aviation Week and Space Technology, Mar. 20, 1989. p. 118.

Council should serve as a "watch dog" to prevent policy change.[30] However, some policy change may be the inevitable result of the U.S. political system and the change in elected officials and broader national policy. Finally, constant policy which supports commercial space, but which is not implemented by concrete action, has not been enough to promote the industry in the past and is unlikely to be enough in the near future.

Provide Short-Term Policy Solutions or Long-Term Goals

The National Space Council effectively provided a short-term solution when it recommended the continued operation of Landsat and greater support for NASP. However, there is also an expectation that the National Space Council should focus on long-term goals.[31] On July 20, President Bush spoke in honor of the twentieth anniversary of the first man walking on the Moon, and endorsed the goal of returning humans to the Moon and then going on to Mars. President Bush stated that this goal should be met in the next century and directed the National Space Council to outline how these goals could be met. The Space Council may find that estimating a time table and costs of such a program is a challenging task to complete in the short term. In addition, the question remains as to whether the council has any enforcement power to see that the program is carried out. It would be impossible for the council to guarantee future funding. For example, President Reagan endorsed both the space station and NASP, but those programs are experiencing funding problems which may jeopardize their completion.

Space Council involvement in NASA and other agencies budget problems for short and long-term programs will be limited by the amount of funding that is available for the space program. Evidently the Space Council will not lobby Congress for additional funds. Executive Secretary Mark Albrecht has stated that they will not seek congressional support for specific NASA programs.[32]

CONCLUSION

The National Space Council was created as of March 1, 1989, and implemented by Executive order in April 1989. One obvious question is how the National Space Council really differs from SIG-Space. In some ways, the two groups are quite similar. They have basically the same membership, although the total membership on the National Space Council is larger by two,[33] which may slow down the policy process. The Council also has the option of claiming executive privilege to keep its deliberations secret. The most important difference is the participation of the Vice President who can draw higher level agency representatives to the meetings.

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[30] Covault, Craig. Potential Increasing for Profitable Ventures. Aviation Week and Space Technology, Apr. 10, 1989. p. 22.

[31] The former Apollo 11 crew called on the National Space Council to Focus on Long-Term Goals, (see Aerospace Daily, May 31, 1989, p. 351), as did the NASA Commercial Programs Advisory Board, (see Defense Daily May 26, 1989, p. 321.)

[32] Defense Daily, June 9, 1989, p. 376.

However, the space community is expecting much more of the National Space Council, especially in providing a more efficient and more open policy coordination mechanism. By removing it from under the auspices of the National Security Council, Congress hoped to make the National Space Council more open and less secretive in its deliberations and policy decisions. In addition, the Vice President, as Chairman, can give the space community increased access to the President. Vice President Quayle's initial activities are a sign that he may continue to be actively involved in the space program. As under the Kennedy Administration, the space program could benefit from a Vice President who is a strong advocate of the space program.

At the same time, however, the National Space Council has different challenges to face than did the National Aeronautics and Space Council during the Kennedy Administration. The current atmosphere is more concerned with budget cutting decisions than the Kennedy-era NASC had to face. It is also important to keep in mind that, although Vice President Johnson was an ardent and very visible supporter of the space program, the NASC may have been most useful and productive when it was involved in behind the scenes coordination. In addition, as noted above, the NASC may have been successful in 1961 because there were important, high level decisions to be made regarding the space program that were unique to that time. If there are not major decisions to be made today, some could consider the Space Council to be unsuccessful while others could believe that the Council has a different role to play than it did in 1961. Dr. Edelson has suggested that the Council should have a broader role to play and should deal with all science and technology issues so that it can make major decisions.[34]

The new council rose to an early challenge when it unanimously agreed and recommended to the President that the Government continue a commitment to Landsat operations and found funding to continue operations through the summer. The Council then took on the issue of what level of commitment the Government should make to the National Aero-Space Plane. The Space Council has many challenges waiting for it, including immediate issues in the FY90 budget, near-term issues in space policy during the Bush Administration, and long-term goals.

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[33] The National Space Council added the Secretaries of Treasury and Transportation, the President's Chief of Staff, and the Director of OMB, although it did not include the Director of ACDA or the Chairman of the Joint Chiefs of Staff, who were SIG-Space members.

[34] Edelson, op.cit.

In asking whether the National Space Council will be successful in meeting today's challenges, one must first define what is meant by success. If success is defined as strong Presidential commitment, then some suggest that President Reagan was as strong a promoter of the space program as any President could be, supporting a strong NASA budget and personally endorsing the space station and the National Aero-Space Plane.[35] If President Bush chooses to be an equally strong supporter, it might change the focus of the National Space Council. If President Bush is not a strong supporter of the space program, the success of the Council may be measured by its ability to draw the President's attention to space issues. However, if success is defined as consensus building between the executive branch and Congress or policy coordination between Government agencies, the Council's success will be less tangible and therefore more difficult to measure.

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[35] Logsdon, John M. Do We Really Need a Space Council? Ad Astra, Feb. 1989. p. 3.

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PREFACE

For nearly a quarter of a century, the U.S. space program enjoyed what can appropriately be termed a "golden age." From the launch of Earth-orbiting satellites, to the visits by robotic spacecraft to Venus and Mars, to the stunning achievement of landing the first human beings on the Moon, the many successes of the space program were exciting and awe-inspiring. The United States was clearly and unquestionably the leader in space exploration, and the nation reaped all the benefits of pride, international prestige, scientific advancement, and technological progress that such leadership provides.

However, in the aftermath of the *Challenger* accident, reviews of our space program made its shortcomings starkly apparent. The United States' role as the leader of spacefaring nations came into serious question. The capabilities, the direction, and the future of the space program became subjects of public discussion and professional debate.

The U.S. civilian space program is now at a crossroads, aspiring toward the visions of the National Commission on Space but faced with the realities set forth by the Rogers Commission. NASA must respond aggressively to the challenges of both while recognizing the necessity of maintaining a balanced space program within reasonable fiscal limits.

Two fundamental, potentially inconsistent views have emerged. Many people believe that NASA should adopt a major, visionary goal. They argue that this would galvanize support, focus NASA programs, and generate excitement. Many others believe that NASA is already overcommitted in the 1990s; they argue that the space agency will be struggling to operate the Space Shuttle and build the Space Station, and could not handle another major program.

Both views reflect concern over the current status of the space program, but each deals with only one aspect of the problem. The space program needs a long-range direction; it also needs the fundamental capabilities that would enable it to move in that direction. A single goal is not a panacea—the problems facing the space program must be met head-on, not oversimplified. But if there are no goals, or if the goals are too diffuse, then there is no focus to the program and no framework for decisions.

The goals of the civilian space program must be carefully chosen to be consistent with the national interest and also to be consistent with NASA's capabilities. NASA alone cannot set these goals, but NASA must lead the discussion, present technically feasible options, and implement programs to pursue those goals which are selected.

We must ask ourselves: "Where do we want to be at the turn of the century?" and "What do we have to do now to get there?" Without an eye toward the future, we flounder in the present. It is not too early to crystallize our vision of the space program in the year 2000. A clear vision provides a framework for current and future programs: it enables us to know which technologies to pursue, which launch vehicles to develop, and which features to incorporate into our Space Station as it evolves.

Leadership in space does not require that the U.S. be preeminent in all areas of space enterprise. The widening range of space activities and the increasing number of spacefaring nations make it virtually impossible for any country to dominate in this way. It is, therefore, essential for America to move promptly to determine its priorities and to pursue a strategy which would restore and sustain its leadership in the areas deemed important.

The Rogers Commission, in its concluding thoughts, states that NASA "constitutes a national resource that plays a critical role in space exploration and development. It also provides a symbol of national pride and technological leadership. The Commission applauds NASA's spectacular achievements of the past and anticipates impressive achievements to come." Only with a clear strategy in place, and its goals for the future defined and developed, will the country be able to regain and retain leadership in space.

Reproduced from Leadership and America's Future in Space; a report to the Administrator by Dr. Sally K. Ride. Washington, National Aeronautics and Space Administration, 1987. p. 5-6, 11-13, 15-19, 21-22, 37-47, 49-55, 57-59.

LEADERSHIP IN SPACE

For two decades, the United States was the undisputed leader in nearly all civilian space endeavors. However, over the last decade the United States has relinquished, or is relinquishing, its leadership in certain critical areas; one such area is the exploration of Mars. With the *Mariner* and *Viking* missions in the 1960s and 1970s, this country pioneered exploration of Mars – but no American spacecraft has visited that planet since 1976. Our current plans for future exploration of Mars include only the *Mars Observer* mission, to be launched in 1992. In contrast, the Soviets have announced a program of extensive robotic exploration of the Martian surface, beginning in 1988 and extending through the 1990s.

The Soviets are now the sole long-term inhabitants of low-Earth orbit. The first, and only, U.S. space station, *Skylab*, was visited by three crews of astronauts before it was vacated in 1974; the U.S. has had no space station since. The Soviets have had eight space stations in orbit since the mid-1970s. The latest, *Mir*, was launched in 1986 and could accommodate cosmonauts and scientific experiments for nearly a decade before the U.S. Space Station can accommodate astronauts in 1995.

The United States has clearly lost leadership in these two areas, and is in danger of being surpassed in many others during the next several years.

The National Space Policy of 1982, which "establishes the basic goals of United States policy," includes the directive to "maintain United States space leadership." It further specifies that "the United States is fully committed to maintaining world leadership in space transportation," and that the civilian space program "shall be conducted ... to preserve the United States leadership in critical aspects of space science, applications, and technology."

Leadership cannot simply be proclaimed – it must be earned. As NASA evaluates its goals and objectives within the framework of the National Space Policy, the agency must first understand what is required to "maintain U.S. space leadership," since that understanding will direct the selection of national objectives.

Leadership does not require that the U.S. be preeminent in all areas and disciplines of space enterprise. In fact, the broad spectrum of space activities and the increasing number of spacefaring nations make it virtually impossible for any nation to dominate in this way. Being an effective leader does mandate, however, that this country have capabilities which enable it to act independently and impressively when and where it chooses, and that its goals be capable of inspiring others – at home and abroad – to support them. It is essential for this country to move promptly to determine its priorities and to make conscious choices to pursue a set of objectives which will restore its leadership status.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities; accordingly, the United States must have, and also be perceived as having, the ability to meet its goals and achieve its objectives.

A U.S. space leadership program must have two distinct attributes. First, it must contain a sound program of scientific research and technology development – a program that builds the nation's understanding of space and the space environment, and that builds its capabilities to explore and operate in that environment. The United States will not be a leader in the 21st Century if it is dependent on other countries for access to space or for the technologies required to explore the space frontier. Second, the program must incorporate visible and significant accomplishments; the United States will not be perceived as a leader unless it accomplishes feats which demonstrate prowess, inspire national pride, and engender international respect and a worldwide desire to associate with U.S. space activities.

National pride and international prestige are two natural benefits of leadership in space. National pride grows as citizens recognize their country's abilities and achievements; international prestige rises as other nations recognize those abilities and achievements.

Perhaps most significant, leadership is also a process. That process involves selecting and enunciating priorities for the civilian space program and then building and maintaining the resources required to accomplish the objectives defined within those priorities. NASA can contribute to this process by: (1) establishing a vision and goals consistent with national space interests; (2) developing and recommending objectives and programs that support those goals; (3) articulating, promoting, and defending them in the political and fiscal arenas; and (4) effectively executing approved programs.

To this end, NASA embarked last fall on a review of its goals and objectives. As NASA Administrator Dr. James Fletcher stated, "It is our intent that this process produce a blueprint to guide the United States to a position of leadership among the spacefaring nations of Earth."

The first step in this necessarily lengthy process was taken by NASA Senior Management's Strategic Planning Council when it adopted the statement in the box on the next page.

This statement reflects the belief that NASA embodies the human spirit's desire to discover, to explore, and to understand. It should be noted that the Space Shuttle and Space Station are not viewed as ends in themselves, but as the means toward achieving the broader goals of the nation's space program. Transportation and orbital facilities support and enable our efforts in science, exploration, and enterprise.

The next step in this process should be to articulate specific objectives and to identify the programs required to achieve these objectives. Of course, in some areas of study the programs have already been identified and are well under way. For example, The Hubble Space Telescope, a general-purpose astronomical observatory in space, is an element of NASA's program to increase our understanding of the universe in which we live; the redesign and requalification of the Space Shuttle's solid rocket booster joint is part of NASA's program to return the Space Shuttle to flight status. However, in other areas, such as piloted exploration, our objectives have not been clearly identified. Does this country intend to establish a lunar outpost? To send an expedition to Mars? What are NASA's major objectives for the late 20th and early 21st Centuries? The Space Shuttle and Space Station will clearly support the objectives, but what will they be supporting?

These questions cannot, of course, be answered by NASA alone. But NASA should lead the discussion, propose technically feasible options, and make thoughtful recommendations. The choice of objectives will shape, among other things, NASA's technology program, the evolution of the Space Station, and the character of Earth-to-orbit transportation.

MEETING THE CHALLENGE IN AERONAUTICS AND SPACE

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set our course into the 21st Century and bring this vision to reality, NASA will pursue major goals which represent its aspirations in aviation and space. These goals are:

- **Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond.**
- **Expand human presence beyond the Earth into the solar system.**
- **Strengthen aeronautics research and develop technology toward promoting U.S. leadership in civil and military aviation.**

Successful pursuit of these major goals requires commitment to the following supporting goals:

- Return the Space Shuttle to flight status and develop advanced space transportation capabilities.
- Develop facilities and pursue science and technology needed for the Nation's space program.

As NASA pursues these goals, we will:

- Promote domestic application of aerospace technologies to improve the quality of life on Earth and to extend human enterprise beyond Earth.
- Conduct cooperative activities with other countries when such cooperation is consistent with our national space goals.

STRATEGIC OPTION DEVELOPMENT

The statement adopted by the Strategic Planning Council describes NASA's mission, its vision, and the scope of its activities. But the next step in the process cannot be taken in the absence of a comprehensive strategy for the civilian space program. Without a coherent formulation of the United States' intentions and priorities, there is no context in which to evaluate the relevance or the importance of any proposed initiatives.

To lay the foundation for the definition and articulation of such a strategy, NASA is currently developing a process to systematically assess the posture of our space program and to refine and assess candidate strategies to direct its future. This process, strategic option development, is still in its early stages; nevertheless, the development of the process has yielded some interesting insights into existing and potential space strategies.

The application of strategic option development to charting the future of the U.S. space program initially evolved from analogies drawn from relevant aspects of business theory. Although it is unconventional to think of space endeavors in terms of a business, many concepts from the business world are applicable and quite useful.

Leadership in business is possible at any time during a product's life cycle. When a new product is introduced (the innovator stage) there is no competition. If the product is successful, the firm becomes the market leader by default. The drawback, of course, is that innovators must accept the high cost and high risk associated with being first. The space program in the early 1960s was an innovator's market. Nearly every successful effort produced a "first," but the risks, as well as the number of failures, were very high.

The launch of America's first astronaut in space, Alan B. Shephard Jr., on the Mercury Redstone II from Cape Canaveral on May 5, 1961.

In a mature business market (the late majority stage) there exists a balance, as many firms compete for some share of the market. At this stage, it is still possible to be a market leader by carving out a particular niche of that market or by delivering the highest quality or best value. The launch vehicle market, for example, is approaching a more mature stage, and many countries will be vying for leadership in the 1990s.

A firm engaged in more than one market must develop an integrated strategy which provides the flexibility to be both an innovator in a new market and the leading competitor in a mature market; this principle should be applied to a space program as well.

The business of space has expanded considerably since the 1960s. The areas of scientific research, space technology, space exploration, and space services are still open to leadership through innovation, but some are also now open to leadership in more mature markets. In fact, national space programs must now look at four stages of space leadership: (1) the *pioneer* stage, innovation in some particular area of research, technology, or exploration; (2) the *complex second* stage, a continuation of a pioneering effort, but with broader, more complex objectives; (3) the *operational* stage, with relatively mature and routine capabilities; and (4) the *commercially viable* stage, with the potential for profit-making.

The activities of a space program can be characterized by physical regions of space: (1) deep space, (2) the outer solar system (the planets beyond the asteroid belt), (3) the inner solar system (the inner planets, the Moon, and the Sun), (4) high-Earth orbit, and (5) low-Earth orbit. Supporting technologies, such as launch capabilities and orbital facilities, are required to undertake all programs.

The complex concept of space leadership may be broken down into logical elements to form a two-dimensional matrix. The columns of the matrix are delineated by the four leadership stages outlined previously; the rows are the five physical regions of possible space activities, with a sixth row for supporting technologies and transportation. Each square of the matrix defines a particular area of possible leadership.

This matrix analysis provides a way to conceptualize alternative courses of action and can be used to describe and assess the space programs of spacefaring nations. It is possible to be a leader in a single square through any of a number of different programs. **Figure 2** illustrates several programs which, if undertaken in the 1990s, would result in leadership in one area of space endeavor. For example, a country could be a leader in the highlighted area of a complex second effort in the inner solar system by successfully establishing a lunar outpost or by sending sophisticated rovers to other worlds.

Not all the squares will be accessible in the next decades. Technology has not progressed to the point that any nation is able to contemplate, for example, commercial prospects in the outer solar system. This figure does not represent a particular strategy; rather, it represents a collection of potential programs.

Being a leader in one area no longer results in overall space leadership. In the early 1960s, the United States and the Soviet Union were the only competitors, and only the cells in the lower left corner of the matrix were accessible. As technology advanced and nations gained experience in space, the opportunities began to expand. In the 1960s, the U.S. learned to send satellites to geosynchronous orbit, scientific experiments to low-Earth orbit, spacecraft to Mars, and even astronauts to the Moon. America was undeniably the leader in space exploration, but the range of space activities was (by today's standards) relatively limited. In the 1980s, not only has the number of spacefaring nations increased, but so has the range of activities that an interested nation might undertake.

The business of space has expanded and branched, and now encompasses such diverse and mature fields as remote sensing, microgravity materials research, commercial communications, and interplanetary exploration. It appears virtually impossible for a single nation to dominate in all space endeavors. Since the U.S. can no longer reasonably expect to lead the way in all activities, it is now important to adopt a strategy to strive for leadership in carefully chosen areas.

If nations engage in similar activities (occupy the same space on the matrix) the conditions exist for either rivalry or cooperation; if a nation engages in distinct activities (occupies a space alone), the conditions exist for uncontested leadership.

This matrix was used to broadly characterize the space programs of the United States and other spacefaring nations during two periods of the space age: (1) 1957 through 1977, illustrated by **Figure 3**; and (2) 1978 through 1990, illustrated by **Figure 4**.

The major programs, U.S. and non-U.S., were identified and placed in the appropriate squares. This is by no means a comprehensive compilation, but the selected activities are representative of space efforts during these periods. An admittedly subjective assessment was made of whether the public perceived the U.S. or non-U.S. efforts to be the leaders in a given square. Each square was then shaded either blue or red: blue if the U.S. was judged the leader, red if not.

A comparison of the two matrices graphically displays the difference between these two periods of time. In the early years of the space age, fewer areas were accessible and the U.S. was the clear leader in most; the matrix representing the 1980s illustrates the decline of U.S. leadership.

LEADERSHIP STAGE REGION OF SPACE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	STAR PROBE	LUNAR OBSERVATORY		
OUTER SOLAR SYSTEM	NEPTUNE FLYBY-PROBE	CASSINI		
INNER SOLAR SYSTEM	MARS SAMPLE RETURN HUMAN EXPEDITION TO MARS	AUTOMATED ROVERS LUNAR OUTPOST	LUNAR BASE	
HIGH-EARTH ORBIT	LARGE SPACE STRUCTURES	ROBOTIC SERVICING	SPACE TRANSFER VEHICLE	SOLAR POWER SATELLITES
LOW-EARTH ORBIT	VARIABLE-G FACILITY	EARTH OBSERVING PLATFORMS	ON-ORBIT ASSEMBLY	MATERIALS PROCESSING
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	NATIONAL AEROSPACE PLANE	SHUTTLE II	ASSURED ACCESS AND RETURN	COMMERCIAL LAUNCH VEHICLES

Figure 2. Possible Programs to Capture Leadership after 1995

Examining the programs of the spacefaring nations shows the basic character of each. The U.S. space program has historically been composed of pioneering efforts – significant firsts and complex second efforts, which emphasized advanced research, technology, and exploration. The general trend can be characterized as revolutionary, producing spectacular events, rather than moderate, evolutionary advances. Even the United States Space Shuttle, though designed to be operational, was a revolutionary concept – it did not evolve from existing launch vehicles.

The Soviet space program, which is radically different from the American program, can be characterized as systematic and evolutionary. The primary focus is not on advanced research and technology, but on incrementally developed operational capabilities, achieved through a strong commitment to a robust infrastructure. The Soviets have steadily evolved toward this operational state and they are now beginning to build on that operational base to move slowly into the commercial arena.

The Europeans and the Japanese appear to be pursuing strategies that combine desires to pursue science in selected areas and to achieve commercial viability in others. The launch system Ariane, the remote-sensing satellite SPOT, and the Japanese JEM (which will be devoted to materials science research) are all examples of elements in these strategies.

These observations suggest that there is no one "correct" strategy; rather, there are many distinct strategic options. Clearly, each nation should choose and pursue a strategy which is consistent with its own national objectives.

What should our choice be? Do we want to mature our operational Earth-orbiting capabilities to a viable commercial enterprise? Should we continue our leadership role in solar system and deep-space exploration? Or should we focus on venturing ever further outward from Earth with human expeditions to the planets?

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	ORBITING ASTRONOMICAL OBSERVATORY-2 HIGH-ENERGY ASTRONOMY OBSERVATORY-1			
OUTER SOLAR SYSTEM	PIONEER			
INNER SOLAR SYSTEM	MARINER SURVEYOR 3 APOLLO 8, 11 VIKING 1 ISEE HELIOS *LUNA* *VENERA*	SURVEYOR 1 APOLLO 15 *ZOND 3*		
HIGH-EARTH ORBIT	SYNCOM 1,2,3 CTS INTELSAT	APPLICATIONS TECHNOLOGY SATELLITE	EARLY BIRD INTELSAT	WESTAR INTELSAT *INTERSPUTNIK* *INMARSAT*
LOW-EARTH ORBIT	ECHO 1 TIROS GEMINI LANDSAT ARIEL 1 *SPUTNIK* *VOSTOK 1*	EXPLORER 1 GEMINI *SOYUZ 4, 5* APOLLO/SOYUZ	TIROS 5	
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	SATURN 5 *SALYUT 1*	SKYLAB *SALYUT*		

* Programs for which the U.S. is not primarily responsible are indicated by italics; areas in which no leadership is perceived are without color

Figure 3. Leadership Matrix: Representative Achievements, 1957 to 1977

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	HUBBLE SPACE TELESCOPE *MIR KVANT MODULE* INFRARED ASTRONOMICAL SATELLITE			
OUTER SOLAR SYSTEM	VOYAGER	GALILEO		
INNER SOLAR SYSTEM	INTERNATIONAL COMET EXPLORER *HALLEY FLOTILLA*	MAGELLAN *VENERA* *ULYSSES* *PHOBOS* *VEGA*	*VENERA*	
HIGH-EARTH ORBIT		GLOBAL POSITIONING SATELLITE INERTIAL UPPER STAGE *GLONASS*	PAYLOAD ASSIST MODULE GLOBAL POSITIONING SATELLITE TDRS	COMMUNICATION SATELLITES INTELSAT
LOW-EARTH ORBIT		SATELLITE REPAIR SPACELAB *SALYUT*	*MIR* *SALYUT*	LANDSAT *SPOT*
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	STS 1 THROUGH 4 USSR SHUTTLE	STS *ENERGIA* *H-I* *ARIANE 4*	TITAN IV *PROTON* *PROGRESS*	ATLAS/CENTAUR TITAN 34D DELTA *ARIANE* *PROTON 3* *LONG MARCH*

* Programs for which the U.S. is not primarily responsible are indicated by italics; areas in which no leadership is perceived are without color

Figure 4. Leadership Matrix: Representative Achievements, 1978 to 1990

LEADERSHIP INITIATIVES

To energize a discussion of long-range goals and strategies for the civilian space program, four bold initiatives were selected for definition, study, and evaluation:

1. **Mission to Planet Earth**: a program that would use the perspective afforded from space to study and characterize our home planet on a global scale.

2. **Exploration of the Solar System**: a program to retain U.S. leadership in exploration of the outer solar system, and regain U.S. leadership in exploration of comets, asteroids, and Mars.

3. **Outpost on the Moon**: a program that would build on and extend the legacy of the Apollo Program, returning Americans to the Moon to continue exploration, to establish a permanent scientific outpost, and to begin prospecting the Moon's resources.

4. **Humans to Mars**: a program to send astronauts on a series of round trips to land on the surface of Mars, leading to the eventual establishment of a permanent base.

The intent is not to choose one initiative and discard the other three, but rather to use the four candidate initiatives as a basis for discussion. For this reason, it was important to choose a set of initiatives which spanned a broad spectrum of content and complexity.

The ground rules for this study are important to understand, since they influenced the detailed definition of the initiatives. The ground rules, set forward at the outset of this study, were:

- The initiatives should be considered *in addition* to currently planned NASA programs. They were not judged against, nor would they supplant, existing programs.
- Each initiative should be developed independently. There is, of course, considerable synergism between certain initiatives. For example, one possible progression for human exploration could be the development of a lunar outpost, followed by an expedition to Mars. However, in order to provide a clear starting point for discussion, the four were considered to be distinct.
- The initiatives should achieve major milestones within two decades.
- The Humans to Mars initiative should be assumed to be an American venture. It was beyond the scope of this work to consider joint U.S./Soviet human exploration.

The candidate initiatives were developed and presented to NASA management to: (1) evaluate the initiatives and their implications, and (2) promote a discussion of the attributes of each initiative to determine the elements which are most important to NASA and to the United States.

Each initiative was developed by a separate task group, which discussed the goals, milestones, and elements of the initiative, and then determined the requisite transportation, space facilities, and technologies. For each initiative, an "advocate" was identified to work with appropriate NASA personnel to develop programmatic details. These four advocates presented the strategies, scenarios, requirements, and rationale to senior NASA management.

Two initiatives, Mission to Planet Earth and Exploration of the Solar System, had a body of recent work from which to draw. The 1986 report of the Earth System Sciences Committee of the NASA Advisory Council, *Earth System Science: A Program for Global Change*, clearly states goals for the future observation of Earth. Two reports by the Solar System Exploration Committee of the NASA Advisory Council similarly articulate goals and recommendations for solar system exploration. Titled *Planetary Exploration through Year 2000: Part One: A Core Program*, and *Part Two: An Augmented Program*, these reports outline both a conservative, steady program for solar system exploration and a set of more challenging, exciting missions to be undertaken if resources to do so become available. The other two initiatives, Outpost on the Moon and Humans to Mars, did not have clearly delineated strategies available and no specific organization within NASA was dedicated to their advocacy.

PROGRAMMATIC ASSESSMENT

Each of the initiatives described in the previous section is a worthwhile program. Although each has something different to offer, each falls within the framework of NASA's vision, each builds on and extends existing capabilities, and each elicits the reaction, "America ought to be doing this." In the absence of fiscal and resource constraints, the United States would undoubtedly adopt all four. In the presence of those very real constraints, and the additional constraints imposed by the current state of our civilian space program, this course of action is not possible.

In its desire to revitalize the civilian space program, NASA must avoid the trap identified by the Rogers Commission during its investigation of the *Challenger* accident: "The attitude that enabled the agency to put men on the moon and to build the Space Shuttle will not allow it to pass up an exciting challenge – even though accepting the challenge may drain resources from the more mundane (but necessary) aspects of the program." The Commission further observed (in reference to the Shuttle flight rates): "NASA must establish a realistic level of expectation, then approach it carefully."

To establish a realistic level of expectation, NASA must consider the current condition of the space program, its strengths and limitations, and its capabilities for growth. Any bold initiative has to begin with and then build on today's space program, which unfortunately lacks some fundamental capabilities. For example, our most critical commodity, Earth-to-orbit transportation, is essential to each of the initiatives. But the Space Shuttle is grounded until at least June of 1988, and when it does return to flight status, the flight rate will be considerably lower than that projected before the *Challenger* accident (a four-Shuttle fleet is estimated to be capable of 12 to 14 flights per year).

In hindsight, it is easy to recognize that it was a crippling mistake to decree that the Space Shuttle would be this country's only launch vehicle. Several studies since the *Challenger* accident have recommended that the civilian space program include expendables in its fleet of launch vehicles. This strategy relieves some of the burden from the Shuttle, gives the country a broader, more flexible launch capability, and makes the space program less vulnerable in the event of an accident.

The problem of limited launch capability or availability will be magnified during the assembly and operation of the Space Station. Currently, NASA plans to use only the Space Shuttle to transport cargo and people to and from the Space Station. This places a heavy demand on the Shuttle (six to eight flights per year), but more important, it makes the Space Station absolutely dependent on the Shuttle. If Shuttle launches should be interrupted again in the mid-1990s, this nation must still have access to

TRANSPORTATION REQUIREMENTS

NASA transportation needs for the 1990s and beyond received considerable attention from the task group and committees examining agency goals and future program thrusts. The consensus of their findings is that if the Nation is to open a "Highway to Space," we must regain regular and assured access to space and expand launch capacity based on expendable and reusable vehicles.

"NASA should, on a most urgent basis, initiate a program to incorporate a diversified family of expendable launchers into its space flight program, to include a heavy-lift ELV. Payloads should be off-loaded from shuttle onto ELVs wherever possible." *Report of the Task Force on Issues of a Mixed Fleet*, 1987

"The U.S. should continue to expand its launch capacity based on a mixed fleet of expendable and reusable launch vehicles to preclude total reliance on any one launch system, so that the present manned and unmanned launchers will remain operationally healthy until the next generation of vehicles is fully developed." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"The use of a mixed launch fleet will allow humans to fly when they are needed on a mission and allow unmanned vehicles to be the carrier of choice for other missions... Diversity will also allow a better matching of the scientific requirements of a mission with the launch capability needed to meet those requirements, rather than forcing the mission to meet the constraints of a single inflexible launch system." *The Crisis in Space and Earth Science*, 1986

"The shuttle fleet will become obsolescent by the turn of the century. Reliable, economical launch vehicles will be needed to provide flexible, routine access to orbit for cargo and passengers at reduced costs ... to reduce space operation costs as soon as possible, the Commission recommends that three major space transport needs be met in the next 15 years: cargo transport to low Earth orbit; passenger transport to and from low Earth orbit; and round-trip transfer beyond low Earth orbit." *Pioneering the Space Frontier*, 1986 space and the means to transport cargo and people to and from the Space Station. The importance of this capability was emphasized by the National Commission on Space in its report, *Pioneering the Space Frontier*: "Above all, it is imperative that the US maintain a continuous ability to put both humans and cargo into orbit."

From now until the mid-1990s, Earth-to-orbit transportation is NASA's most pressing problem. A space program that can't get to orbit has all the effectiveness of a navy that can't get to the sea. America must develop a cadre of launch vehicles that can first meet the near-term commitments of the civilian space program and then grow to support projected programs or initiatives.

Expendable launch vehicles should be provided for payloads which are not unique to the Space Shuttle – this is required just to implement current plans and to satisfy fundamental requirements.

A Shuttle-derived cargo vehicle should be developed immediately. A Shuttle-derived vehicle is attractive because of its lift capacity, its synergism with the Space Transportation System, and its potential to be available for service in the early 1990s. This cargo vehicle would reduce the payload requirements on the Shuttle for Space Station support and would accelerate the Space Station assembly sequence.

The United States should also seriously consider the advisability of a crew-rated expendable to lift a crew capsule or a logistics capsule to the Space Station. The logistics vehicle, for Space Station resupply and/or instrument return, would be developed with autodocking and precision reentry capabilities. The crew capsule would carry only crew members and supplies, would launch (with or without a crew) on the expendable vehicle, would have autodocking capability, and might also be used for crew rescue.

TECHNOLOGY

Rebuilding the Nation's technology base is essential for the successful achievement of any long-term space goal. It is widely agreed that we are living off the interest of the *Apollo* era technology investment, and that it is time to replenish our technology reservoir in order to enhance our range of technical options.

"The Nation has allowed its technology base to erode, leaving it with little capability to move out in new directions should the need arise." Letter from Daniel J. Fink (Chairman, NASA Advisory Council) to James Fletcher, dated August 14, 1986

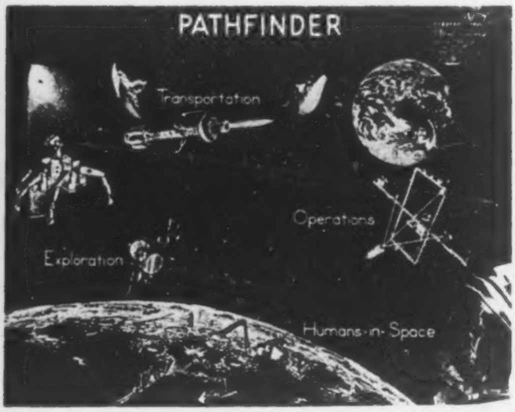
"Space technology advancement underlies any comprehensive future space activity. The present course is a status-quo caretaker path with no potential growth. New commitments are called for in key technologies such as propulsion, automation and robotics, flight computers, information systems, sensors, power generation, materials, structures, life support systems, and space processing. We support the recommendation by the National Commission on Space for a three-fold increase in this relatively low-budget but extremely important area of space technology advancement, especially in view of strong foreign commitments to such technology development." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"Research must be pursued on a broad front, to identify and quantify technical possibilities before their usefulness can be judged. Such a research and technology program is therefore properly conceived as opportunity generating, not directed toward applications." *Pioneering the Space Frontier*, 1986

These transportation capabilities are required just to launch, assemble, operate, and safely inhabit the Space Station, and to have some prospect of being able to support future initiatives.

Without sound, reliable Earth-to-orbit transportation available to lift sensors, spacecraft, scientists, and explorers to orbit, we will not be in a position to aggressively pursue either science or exploration. We have stated that transportation is not our goal – but it is essential to the successful pursuit of whatever goals we choose. If we do not make a commitment now to rebuild and broaden our launch capability, we will not have the option of pursuing any of the four initiatives described in the previous section.

The same can be said for advanced technology. The National Commission on Space observed that "NASA is still living on the investment made [during the *Apollo* era], but cannot continue to do so if we are to maintain United States leadership in space." Several recent studies concur, concluding that our technology base has eroded and technological research and development are underfunded. The technology required for bold ventures beyond Earth's orbit has not yet been developed, and until it is, human exploration of the inner solar system will have to wait.



Technologies explored by Project Pathfinder.

Project Pathfinder has been developed by NASA's Office of Aeronautics and Space Technology in conjunction with experts on the Lunar and Mars initiatives. Pathfinder would provide the technologies to enable bold missions beyond Earth's orbit: technology for autonomous systems and robotics, for lunar and planetary advanced propulsion systems, and for extraction of useful materials from lunar or planetary sources. It also deals in a significant way with the human ability to live and work in space, by developing technologies for life-support systems and the human/machine interface. Until advanced technology programs like Project Pathfinder are initiated, the exciting goals of human exploration will always remain 10 to 20 years in the future.

Life sciences research is also critical to any programs involving relatively long periods of human habitation in space. Because the focus of our life sciences research for the last several years has been on Space Shuttle flights, which only last for five to ten days, there has been no immediate need for a program to study the physiological problems associated with longer flights. Without an understanding of the long-term effects of weightlessness on the human body, our goal of human exploration of the solar system is severely constrained.

Before astronauts are sent into space for long periods, research must be done to understand the physiological effects of the microgravity and radiation environments, to develop measures to counteract any adverse effects, and to develop medical techniques to perform routine and emergency health care aboard spacecraft.

Project Pacer, developed by NASA's Office of

Space Science and Applications, is a focused program designed to develop that understanding and provide the physiological and medical foundation for extended spaceflight. This research would be conducted in laboratories and on Space Shuttle missions in preparation for the critical long-term experiments to be conducted on the Space Station.

Until the Space Station is occupied, and actual long-duration testing is begun, we will lack the knowledge necessary to design and conduct piloted interplanetary flights or to inhabit lower-gravity surface bases. Although the research conducted prior to the occupation of Space Station cannot provide definitive answers to several key questions, it is an essential precursor to the research and technology development on the Space Station.

LIFE SCIENCES RESEARCH

The prospect of an extended human presence in space on the Space Station and later on extended missions to the Moon or Mars requires a commitment to better understand and respond to biomedical, psychological, and human engineering challenges. Although there is great confidence that we will eventually establish a presence on other bodies in the solar system, there remains uncertainty in the medical community about the implications of such journeys for human health, safety, and productivity. A number of recent studies highlight concerns and identify areas requiring additional research.

"Space medicine is unique in the context of the other space sciences – primarily because, in addition to questions of fundamental interest, there is a need to address those issues that are more of a clinical or human health and safety nature ... if this country is committed to a future of humans in space, particularly for long periods of time, it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed. Not to do so would be imprudent at best – quite possibly, irresponsible." *A Strategy for Space Biology and Medical Science*, 1987

"Many crucial issues in the three major areas of health, life support, and operational capabilities remain to be resolved before the safety of humans working in space over months and years can be assured. Certain aspects of physiological adaptation to microgravity may be life-threatening, especially over the long-term ... Areas such as medical care, radiation protection, environmental maintenance, and human productivity are equally serious, but the research and development activities associated with these areas have at least begun on a modest scale. To neglect any of these areas could prove risky, and parallel research activities are recommended." *Advanced Missions with Humans in Space*, 1987

"Of paramount practical importance are human safety and performance. Long-duration flights on the Space Station will increase our understanding of the effects of the space environment on people and other living systems. Problems of bone demineralization and loss of muscle mass persist, and effective empirical solutions are unlikely to be found soon ... It is imperative that basic research on this problem continue, both on the ground and in space." *Pioneering the Space Frontier*, 1986

Both technology development and life sciences research are pacing elements in human exploration.

The four initiatives represent widely varying levels of complexity and commitment. As part of the development and evaluation of the initiatives, an assessment was performed to estimate their relative complexities and therefore their relative impacts on the agency and its resources. The initiatives, and results from related studies, were reviewed to identify the required technology, transportation, on-orbit facilities, and precursor science. This assessment yielded the elements comprising each initiative – the building blocks of that initiative.

The assessment sought to define the initiatives to a reasonable level of detail through 2010. At this time, the initiatives would be in different stages of development. All Earth observing platforms would be in space with their observing systems operating; they would be serviced periodically, and would continue to transmit data to Earth for years. The final mission of the Planetary initiative would be complete; this initiative is not defined past 2010. The Lunar outpost would be well established, with most surface elements developed and delivered; it would receive continuing logistics support, but would be somewhat self sustaining, and have considerable potential for growth and for support of further exploration activities. In 2010, the nation's Mars program would have just finished its human reconnaissance phase, and would be prepared to embark on the establishment of an outpost.

To provide a common starting point for each initiative, this analysis assumed the currently planned NASA space program as a foundation. That is, each initiative must be built from the foundation of a fleet of four Space Shuttles and a Phase 1 Space Station; everything else that would have to be added to accomplish the initiative, including additional Space Station modules, new transportation elements, unscheduled precursor science missions, etc., was assumed to be part of that initiative.

Some of the elements of each initiative would be developed solely for that initiative; many others could be common to other intitiatives as well. An example of the former is the lunar oxygen plant designed to extract oxygen from the lunar soil. Although similar technologies might eventually be needed at a Mars outpost, the element itself exists only in the Lunar initiative. An example of an element which could be common to several programs is the space transfer vehicle of the Earth initiative. Although it would lift geostationary platforms from the Space Station to their final orbit, this vehicle could also be used to deliver other cargo (unrelated to the Earth initiative) to geosynchronous orbit, or it could be the basis of a lunar transfer vehicle. Each initiative has elements which could be

	PLANETARY	EARTH	LUNAR	MARS
● EARTH TO ORBIT VEHICLES				
- SPACE SHUTTLE	*	●	●	●
- PERSONNEL CARRIER			●	●
- HEAVY-LIFT LAUNCH VEHICLE	●	●	●	●
- EXPENDABLE LAUNCH VEHICLE	●	●	●	●
- SIGNIFICANT RETURNED CARGO			●	●
● SPACE TRANSFER VEHICLES				
- ORBITAL MANEUVERING VEHICLE	*	●	●	●
- CABIN			●	●
- TELEROBOTIC SERVICER		●	●	●
- EXPENDABLE UPPER STAGES	●	●	●	●
- GEOSTATIONARY TRANSFER VEHICLE		●		
- CARGO TRANSFER VEHICLE			●	●
- PERSONNEL TRANSFER VEHICLE			●	●
* REQUIRED TO RECOVER MARS SAMPLE				

Table 1.
Transportation Requirements for the Initiatives

common to other programs, as well as initiative-specific elements.

An overview of the transportation elements required for the initiatives is shown in **Table 1**. The Earth and Planetary initiatives make the most modest demands on transportation, in terms of both essential new capabilities and frequency of use. But each of the initiatives requires an Earth-to-orbit transportation system comprised of more than just a Space Shuttle fleet.

A heavy-lift launch vehicle is either enabling, or significantly enhancing, to all the initiatives. A Shuttle-derived vehicle would have sufficient

SPACE STATION EVOLUTION

The Phase 1 Space Station will be a permanently staffed "laboratory in space" by 1996. Other capabilities, such as an assembly station or a fueling depot, will not be included in the initial phase, but could be accommodated later if a need for those functions is clearly identified.

A key question for the not-too-distant future is "How should the Space Station evolve?" Since the Space Station is a means to pursue our goals, the answer depends on what those goals are. It is important to understand what each initiative demands of the Space Station. For example, the Planetary initiative makes few demands on the Space Station; the Mars initiative makes substantial demands.

NASA's Office of Space Station has set up a Strategic Plans and Programs Division whose charter is to understand how the Space Station would be required to evolve under a variety of scenarios for the future, and what provisions must be made in the design of the Phase 1 Space Station to ensure that the evolution is possible.

Space Station evolution workshops, held in September 1985 and July 1986, laid the foundation for understanding how to accommodate a variety of users whose requirements may not be compatible. These workshops recognized, for example, that a laboratory in space, featuring long-term access to the microgravity environment, might not be compatible with an operational assembly and checkout facility, as construction operations could disturb the scientific environment.

Artist's conception of the Phase 1 Space Station.

Space Station evolution planning will include an assessment of the implications of each of the four initiatives. It is important to have specific scenarios, with a level of technical definition behind them, to serve as a basis for these assessments. It is also important that results from these assessments feed back into the initiative scenarios. This iterative approach is required to establish reasonable evolution scenarios and initiatives that are compatible with the proposed evolution.

capacity for the Earth and Planetary initiatives. It would also satisfy the requirements of the Mars and Lunar initiatives through the 1990s, although shortly after the turn of the century both would need a vehicle with a lift capacity of 150,000 to 200,000 pounds. This higher lift capacity is needed primarily to supply the large amounts of propellant required for each initiative (about 2.2 million pounds to low-Earth orbit for each Mars sprint mission; 200,000 pounds to low-Earth orbit for each lunar trek).

The Lunar and Mars initiatives also have a critical need for the capability to transport personnel to and from the Space Station. This need could be filled by a personnel module added to the Shuttle, or by some other personnel carrier. The additional crew members would perform on-orbit assembly of the cargo and crew vehicles. Although there is currently no good estimate of the size of the crew required to assemble and test a vehicle in orbit, it is likely that the Lunar initiative, if it develops as projected in Phase III, would require more than 30 people in low-Earth orbit by the year 2010. It builds to this peak gradually, though, and the early assembly requirements (2000 to 2005) can be phased in slowly.

All the initiatives have other needs as well. The Planetary initiative's needs are limited to expendable stages, and possibly an Orbital Maneuvering Vehicle for the recovery of a returned Mars sample. The Earth initiative makes more substantial use of Earth-orbital transportation, including a transfer vehicle to lift fully assembled observing platforms from the Space Station to geosynchronous orbit, and sophisticated Orbital Maneuvering Vehicles to aid in platform servicing. The Lunar and Mars initiatives are more demanding. Both are likely to require Orbital Maneuvering Vehicles to transport personnel from the Space Station to orbital assembly sites. Most significant, both require substantial space transfer vehicles to transport crews from low-Earth orbit to either the Moon or Mars. Although the lunar transfer vehicle could be a derivative of a transfer vehicle to geosynchronous orbit (or vice versa), at this time it appears that the Mars transfer vehicle will demand a different design.

The orbital facilities required for each initiative are shown in **Table 2**. The Planetary initiative has limited requirements in this area; the other three have extensive needs that begin with the Phase 1 Space Station. The Phase 1 Space Station includes polar platforms and attached payloads for the Earth initiative; it serves as a technology and systems test bed for the Lunar initiative; and it will be a crucial laboratory for life sciences research and technology development for the Mars initiative.

	PLANETARY	EARTH	LUNAR	MARS
● LOW-EARTH ORBIT FACILITIES				
- PHASE I SPACE STATION		●	●	●
- SPACE STATION ADDITIONS				
- LIFE SCIENCE RESEARCH				●
- SAMPLE ISOLATION	●			●
- SPACE TRANSFER VEHICLE ASSEMBLY AND OPERATIONS			●	●
- ADDITIONAL CREW			●	●
- PROPELLANT STORAGE			●	●
- POLAR PLATFORMS		●		
● GEOSTATIONARY FACILITIES				
- PLATFORMS		●		
- COMMUNICATIONS			●	●
● LUNAR FACILITIES				
- SERVICE STATION			●	
- COMMUNICATIONS			●	
● MARS FACILITIES				
- CARGO VEHICLE ORBITAL OPERATIONS				●

Table 2.
Orbital Facilities Required for the Initiatives

All the initiatives require that the Space Station evolve additional capabilities, but the needs of the Planetary initiative (a sample return module) and the Earth initiative (servicing capability, operation of a space transfer vehicle) are relatively modest. The Lunar initiative requires gradual evolution to support the assembly, servicing, and checkout of lunar transfer vehicles. This requires more people in orbit (and therefore more Space Station modules and logistics traffic), spaceport facilities, and a propellant depot. The Mars initiative also relies on those spaceport facilities and additional crew accommodations, and although it will not occur quite as soon as in the Lunar initiative, the assembly of the large Mars cargo and piloted vehicles will be a significant task.

The Lunar initiative includes significant surface facilities such as habitation modules, laboratory modules, and an oxygen plant; the Mars initiative looks toward an eventual outpost (after 2015), but while similar surface facilities would be necessary at that time, they have not been included in the assessment to 2010. The Lunar and Mars initiatives both require landers, ascent vehicles, and rovers. These would most likely use some common technologies and subsystems, but they would not be identical.

The initiatives also require investments in technology development, and investments in institutional and human resources. This support early in the life of an initiative is vital to its success. The level of investment required is directly proportional to the magnitude and complexity of the initiative. The Earth and Planetary initiatives would be expected to have relatively modest needs; the Lunar and Mars initiatives would demand substantial technology development programs, and significant increases in highly skilled personnel and institutional facilities. The need for a dedicated, enthusiastic, and technically competent workforce must not be minimized; the Lunar and Mars initiatives would both require a significant increase in human resources.

The current level of definition of the initiatives, particularly the Lunar and Mars initiatives, is not adequate to reasonably estimate their costs. But while it was not appropriate to attempt to determine the absolute level of resources required by each, it was reasonable to estimate the relative levels through 2010. For each initiative, after the elements not included in current NASA plans were identified, the mass and size of each were estimated in order to determine the transportation requirements for that initiative. There was no attempt, at this early stage, to optimize the transportation system.

Figure 14 compares the resources required by the four initiatives during the next five years. It is important to understand the level of effort needed to support a new initiative during this period, since the country will also be relying on the civilian space program to return the Shuttle to flight, to reinvigorate its transportation system, and to continue serious preparations for the Space Station.

The Lunar, Earth, and Planetary initiatives would take about the same level of investment through 1992. The investment in the Lunar initiative would be primarily in technology and in early transportation development; in the Earth initiative, it would be largely in the development of the polar platforms, data handling system, and transportation; in the Planetary initiative, it would be primarily in technology, and in readying the *Comet Rendezvous Asteroid Flyby* mission for a 1993 launch.

The Mars initiative requires the largest commitment in the early years. This would be primarily an investment in transportation elements and in life science related additions to the Space Station. Transportation and Space Station use have not been optimized, so some reduction might be possible. The message, however, would not change: the country would have to make a major investment in the next five years to land people on Mars in 2005.

The complexity of both the Lunar and Mars initiatives in the year 2000 demands technology developments early in the program. Thus, through 1992 the majority of the Lunar initiative, and a significant portion of the Mars initiative, would be comprised of those technology activities which lay the groundwork for the initiative. Like early work in transportation, there is considerable synergism in the early technology requirements of these two initiatives.

Figure 15 compares the initiatives through 2010. The Lunar and Mars initiatives are nearly an order of magnitude greater in programmatic scope than the Planetary and Earth initiatives. The levels of investment in the Earth and Planetary initiatives peak in the early-to-mid-1990s, and then decrease to levels which remain fairly constant through the first decade of the next century. The Lunar initiative does not require extraordinary resources through 1992, but the commitment builds substantially in the mid-1990s. It peaks in about 2000, at the time of this initiative's first human landing, and stays high through 2010 as the outpost is developed into a permanent base. The total level of effort through 2010 is large, and reflects the ambitious approach to the construction of the lunar base. However, the nature of this initiative allows considerable flexibility. For example, the outpost materials could be delivered to the surface rapidly or at a more deliberate pace; certain capabilities of the outpost could be emphasized and developed before others; or the transition from a temporarily occupied outpost to a large

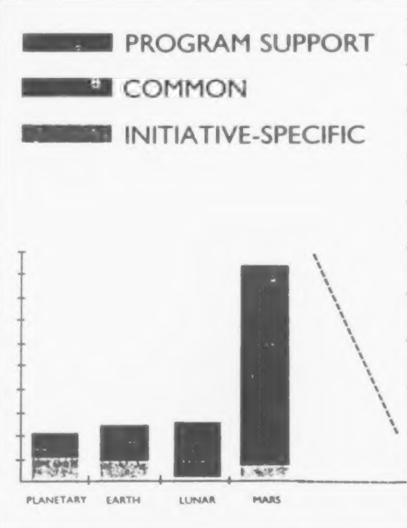


Figure 14.
Resources Required by Initiatives through 1992

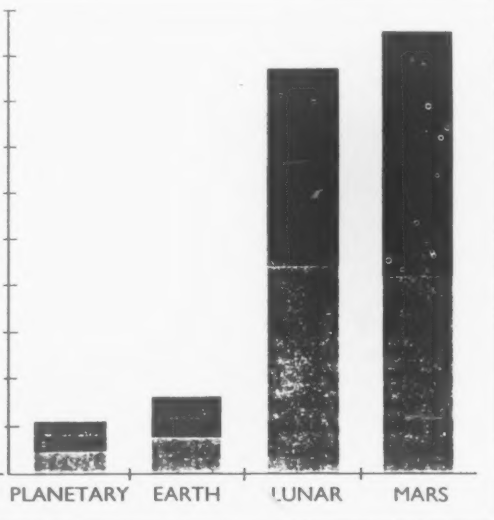


Figure 15.
Resources Required by Initiatives through 2010

permanently staffed base could be delayed. Any of these options would significantly reduce the investment through 2010.

Although the Mars initiative offers the greatest amount of human and technological drama, it also demands the greatest investment. The Mars initiative definition included only those elements required for the three sprint missions, the last in 2010, so the level of investment shown is artificially low between 2005 and 2010. The magnitude of the initiative indicates a large commitment of resources, and the timescale dictates that the investment peak in about 2000.

It is possible to reduce the early investment to a level comparable to that of the other three initiatives by allowing the first human landing to occur in 2010, rather than in 2005. The 2005 landing was selected at the outset to achieve the major milestone within two decades, but this analysis suggests that this ground rule may not be appropriate for the Mars initiative.

EVALUATION OF INITIATIVES

To this point, we have been considering four specific initiatives, each of which would, if adopted, provide leadership in a particular area of space endeavor. Now it is important to differentiate between an initiative and a strategy. A strategy provides an overall framework and direction; it identifies and prioritizes goals, and defines a course to attain them. An initiative should be an element of a strategy; a part, but only a part, of the larger picture. Initiatives would, of course, be best judged in the context of a strategy.

A process to define and evaluate candidate strategies for the civilian space program is being developed at NASA. This process will seek to identify possible strategies, then assess the likelihood of success and possible implications of each. They will be evaluated in relation to the existing and projected environment, and to the various conditions which may influence their success, such as:

- NASA's strengths, its weaknesses, and its culture
- External threats to U.S. leadership
- Opportunities to exercise leadership
- Optimistic and pessimistic scenarios of uncontrollable factors which influence NASA and its ability to carry out its charter
- The existing U.S. space policy

A successful Mars Rover/Sample Return *mission blasts off, carrying its cargo of Martian samples back to Earth.*

As potential strategies are modified in light of these factors, the result should be a set of two or three distinct, viable strategies whose resource requirements, threats to success, and implications to NASA and the nation are well defined and understood. Although this process is being developed at NASA, it is not NASA's role to determine the overall strategy for the nation's civilian space program; that must be a national decision. NASA should, however, be prepared to present viable options. The potential benefit of this process is evident. It can result in a cohesive strategy that is consistent with national goals, is based on a realistic appraisal of NASA's strengths and weaknesses and the nation's willingness to pursue it, and is resilient to changes in the international environment.

Ideally, of course, a strategy would already be in place. Then each initiative could be judged in light of its compatibility with the overall plan.

While stressing the need for a comprehensive strategy, we can nevertheless conduct a preliminary assessment of the initiatives, recognizing that the important considerations are the quality of the program, NASA's ability to carry it out, and the public's willingness to support it. In the process of this evaluation, we can see the elements of a potential strategy begin to emerge.

Exploration of the Solar System

In the 1960s and 1970s, planetary exploration was a vital and important component of the United States space program. However, while other nations are now vigorously pursuing solar system exploration, the U.S. has launched no planetary missions since 1978.

What does the next decade hold in store? The Soviets have announced their intent to launch three ambitious flights to Mars by 1995, and a Mars sample return mission by 2000. If they are successful with their new-generation spacecraft, and can continue to forge cooperative agreements with European nations, they will clearly have the greater momentum in the exploration of Mars by the mid-1990s.

The Chairman of the NASA Advisory Council's Solar System Exploration Committee has expressed his concern about more than the exploration of Mars: "If we do not continue to carry out these challenging missions to the outer planets and comets and asteroids, we will quickly lose the limited momentum still remaining."

The Solar System Exploration Committee has devised a strategy for planetary exploration through the year 2000, which presented "the minimum-level program that could be carried out in a cost-effective manner, and would yield continuing return of scientific results." NASA should embrace this Core Program.

The *Mars Rover/Sample Return* mission is the centerpiece of the Solar System Exploration Committee's recommended augmentation to its Core Program. This is a mission of bold scientific exploration and high technological drama, and a necessary precursor to the human exploration of Mars. The option for a 1998 launch (two years later than the 1996 date proposed in the initiative) should be preserved.

Although the *Mars Rover/Sample Return* was presented as a U.S. mission in this initiative, it could be performed in cooperation with our allies and/or in coordination with the Soviet Union. In fact, planetary exploration is well suited to international cooperation. The U.S. could benefit significantly by coordinating its *Mars Observer* with the three sophisticated Soviet missions to be launched for Mars over the next seven years. Coordination of these early flights, and exchange of resulting data, would leave the U.S. better prepared to undertake a *Mars Rover/Sample Return* mission, whether in coordination with the Soviets or alone.

Planetary exploration need not be NASA's primary focus, but it offers opportunities to exercise leadership in the international arena through organizing and participating in coalitions to achieve objectives which are consistent with U.S. goals, and it can provide important precursor information for either of the larger human exploration initiatives.

Robotic planetary exploration should be actively supported and nurtured within NASA. Although it does not have the immediate relevance of the Mission to Planet Earth, or the excitement of human exploration, it is fundamental science that challenges our technology, extends our presence, and gives us a glimpse of other worlds. As such, it enjoys widespread public interest and support. Although not necessarily at the pace suggested in this initiative, planetary exploration must be solidly supported through the 1990s.

Mission to Planet Earth

Mission to Planet Earth is not the sort of major program the public normally associates with an agency famous for *Apollo*, *Viking*, and *Voyager*. But this initiative is a great one, not because it offers tremendous excitement and adventure, but because of its fundamental importance to humanity's future on this planet.

This initiative directly addresses the problems that will be facing humanity in the coming decades, and its continuous scientific return will produce results which are of major significance to all the residents of the planet. The benefits are clear to a public that is increasingly concerned about global environmental problems like ozone depletion, buildup of greenhouse gases, and acidification of lakes and forests. And as the environment and its preservation become more pressing issues, the initiative retains its importance for many generations to come.

For this reason it should enjoy sustained public and Congressional support and interest. The U.S. is the only country currently capable of leading a Mission to Planet Earth, but the program is designed around, and requires, international cooperation. Admittedly, the initiative's international scope could complicate its coordination and implementation, but the concept embodied in the initiative enjoys widespread international support. As more and more countries are facing ecological problems, there is increasing interest in a global approach. In fact, this concept is supported by several international organizations, and may emerge as a theme for the International Space Year, 1992. This initiative represents an important opportunity for the United States to exercise leadership in an increasingly significant area.

As the Earth System Sciences Committee suggests, NASA is a natural leader for a Mission to Planet Earth. The National Science Foundation and the National Oceanic and Atmospheric Administration will play important roles, and interagency coordination is crucial. But since the major focus is on observations from space and the coordination and analysis of these (and ground-based) observations, NASA is uniquely suited to lead the effort. It is a natural use for, and extension of, our low-Earth orbital facilities and capabilities, and would not severely drain resources from existing programs. This is an initiative well within NASA's capabilities, and could be carried out with our traditional commitment to excellence.

Should NASA do it? Virtually everyone exposed to this initiative recognized its fundamental importance, and agreed that "whatever we do, we have to do this"; but some felt it may not be bold and visionary enough to stimulate the increased funding necessary. The National Commission on Space conducted numerous public sessions on the space program, and solicited and received comments from a wide cross-section of Americans. The Commission's report lists a series of points "brought forward repeatedly" in those public sessions. One of these was the concern that "any new push into space must supplement living on Earth.... Don't abandon our home planet!"

Plans are already under way within NASA to undertake a subset of this program. The Earth Observing System, which consists of two NASA polar platforms, is being coordinated with the corresponding activities of the European Space Agency and Japan. The first NASA platform is part of the Phase 1 Space Station. The second platform, the instruments, and the payloads remain unapproved. And although the Earth Observing System would represent a major start, it is not sufficient to fulfill all the objectives of this initiative. Critical activities for the immediate future include the coordination of Federal agencies, and the strengthening of international agreements to facilitate the coordination of this international effort.

NASA should embrace Mission to Planet Earth. This initiative is responsive, time-critical, and shows a recognition of our responsibility to our home planet. Do we dare apply our capabilities to explore the mysteries of other worlds, and not also apply those capabilities to explore and understand the mysteries of our own world – mysteries which may have important implications for our future on this planet?

Humans to Mars

Exploring, prospecting, and settling Mars are clearly the ultimate goals of the next several decades of human exploration. But what strategy should be followed to attain those goals?

Any expedition to Mars is a huge undertaking, which requires a commitment of resources which must be sustained over decades. This task group has examined only one possible scenario for a Mars initiative – a scenario designed to land humans on Mars by 2005. This timescale requires an early and significant investment in technology; it also demands a heavy-lift launch vehicle, a larger Shuttle fleet, and a transportation depot at the Space Station near the turn of the century. This would require an immediate commitment of resources and an approximate tripling of NASA's budget during the mid-1990s.

More important, NASA would be hard pressed to carry the weight of this ambitious initiative in the 1990s without severely taxing existing programs. NASA's available resources were strained to the limit flying nine Shuttle flights in one year. It will be difficult to achieve the operations capacity to launch and control 12 to 14 Shuttle flights per year, and assemble, test, and continuously operate a Space Station in the mid-1990s. It would not be wise to embark on an ambitious program whose requirements could overwhelm those of the Shuttle and Space Station during the critical next decade.

This suggests that we should revise the ground rules and consider other approaches to human exploration of Mars. One alternative is to retain the scenario developed here, but to proceed at a more deliberate (but still aggressive) pace, and allow the first human landing to occur in 2010. This spreads the investment over a longer period, and though it also delays the significant milestones and extends the length of commitment, it greatly reduces the urgency for Space

Station evolution and growth, and consequently for transportation capabilities as well.

We must pursue a more deliberate program; this implies that we should avoid a "race to Mars." There is the very real danger that if the U.S. announces a human Mars initiative at this time, it could escalate into another space race. Whether such a race was real or perceived, there would be constant pressure to set a timetable, to accelerate it if possible, and to avoid falling behind. Schedule pressures, as the Rogers Commission noted, can have a very real, adverse effect. The pressure could make it difficult to design and implement a program which would have a strong foundation and adequate momentum to sustain itself beyond the first few piloted missions. This could turn an initiative that envisions the eventual development of a habitable outpost into another one-shot spectacular. Such a dead-end venture does *not* have the support of most NASA personnel. Neither, according to the National Commission on Space, does it have the support of the public. A "theme brought forward repeatedly" in the Commission's extensive public sessions was "a strong wish that our next goal for piloted space activity not be another *Apollo* – a one-shot foray or a political stunt."

THE OFFICE OF EXPLORATION

During the majority of this work, there was no focal point within NASA for studies on human exploration. Recognizing this deficiency, and adopting one of the early recommendations of this study, the NASA Administrator has established the Office of Exploration to fund, direct, and coordinate studies related to human exploration.

Both of the human exploration initiatives described in this work were generated in a workshop or task force environment. The three to four months devoted to their formulation were adequate only to develop the starting point for in-depth studies. The Office of Exploration will be responsible for coordinated mission studies to develop these and other scenarios, to assess mission concepts and schedules, and to study trade-offs in requirements, technology, transportation, and facilities utilization. Advanced technology and transportation requirements cannot be developed in a vacuum. These mission studies will provide a context for planning technology and transportation development and Space Station evolution (and studies in these areas will, of course, feed back into the mission scenarios).

The establishment of the Office of Exploration was an important step. Adequate support of the Office will be equally important, and will be an indication of the commitment to long-term human exploration. There is some concern among observers that the Office was created only to placate critics, not to provide a serious focus for human exploration. Studies relating to human exploration of the Moon or Mars currently command only about .03 percent of NASA's budget (approximately 1 dollar out of 3000); this is not enough.

The scenario described in this report is a rational, sustained program, leading to an outpost and eventual permanent base on Mars. But there is some fear that it is susceptible to transformation into a stunt. This could mortgage the viable space program we hope to have in the 1990s for a "spectacular," which may have few lasting benefits.

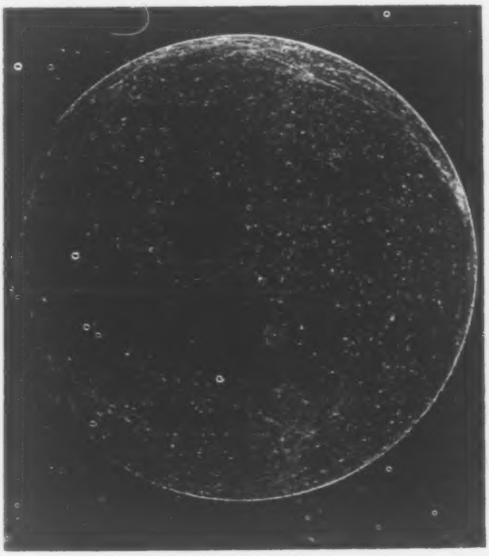
Settling Mars should be our eventual goal, but it should not be our next goal. Sending people to and from Mars is not the only issue involved. Understanding the requirements and implications of building and sustaining a permanent base on another world is equally important. We should adopt a strategy of natural progression which leads, step by step, in an orderly, unhurried way, inexorably toward Mars.

Outpost on the Moon

The Lunar initiative is a logical part of a long-range strategy for human exploration. The National Commission on Space recommended that the U.S. follow a "natural progression for future space activities within the solar system," and concluded that the natural progression of human exploration leads next to the Moon.

The establishment of a lunar outpost would be a significant step outward from Earth – a step that combines adventure, science, technology, and perhaps the seeds of enterprise. Exploring and prospecting the Moon, learning to use lunar resources and work within lunar constraints, would provide the experience and expertise necessary for further human exploration of the solar system.

The Lunar initiative is a major undertaking. Like the Mars initiative, it requires a national commitment that spans decades. It, too, demands an early investment in advanced technology, Earth-to-orbit transportation, and a plan for



Space Station evolution. Even considering its gradual evolution over the first five years, the ambitious buildup of the lunar outpost envisioned in this scenario would require a high level of effort in the mid-to-late 1990s, and would place substantial demands on transportation and orbital facilities. This is a period when resources may be scarce.

However, this initiative is quite flexible. Its pace can be controlled, and more important, adapted to capability. It is possible to lay the foundation of the outpost in the year 2000, then build it gradually, to ease the burden on transportation and Space Station at the turn of the century.

The Lunar initiative is designed to be evolutionary, not revolutionary. Relying on the Space Station for systems and subsystems, for operations experience, and for technology development and testing, it builds on and gradually extends existing capabilities. Many of the systems needed for reaching outward to Mars could be developed and proven in the course of work in the Earth-Moon region. It is not absolutely necessary to establish this stepping stone, but it certainly makes sense to gain experience, expertise, and confidence nearer Earth first, and then to set out for Mars.

This study did not include an assessment of the level of public support for these initiatives. However, there is considerable sentiment that *Apollo* was a dead-end venture, and we have little left to show for it. Although this task force found some who dismissed this initiative because "we've been to the Moon," it found many more who feel that this generation should continue the work begun by *Apollo*.

Although explorers have reached the Moon, the Moon has not been fully explored. This initiative would push back frontiers, not to achieve a blaze of glory, but to explore, to understand, to learn, and to develop; it would place the Apollo Program into a broader context of continuing exploration, spanning several generations of Americans. And it fits beautifully into a natural progression of human expansion that leads "from the highlands of the Moon to the plains of Mars."

CONCLUSION

Over the last 25 years, as a result of the success of programs like *Apollo*, *Skylab*, *Viking*, *Voyager*, and the Space Shuttle, the American public has come to expect this country to lead the world in space science, space exploration, and space enterprise. But during the 1980s, membership in the once-exclusive club of spacefaring nations has grown, and our leadership is being challenged in many areas.

In today's world, America clearly cannot be the leader in all space endeavors. But we will be the leader in very few unless we move promptly to develop a strategy to regain and retain leadership in those areas we deem important.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities. Thus, the strategy we choose must lay a strong foundation of scientific research and technology development, and must include visible, significant accomplishments that demonstrate the successful pursuit of our stated goals.

To stimulate a discussion of the future of the U.S. civilian space program, four potential leadership initiatives were developed. Each fits comfortably under the umbrella of NASA's charter, each contains visible milestones within the next two decades, and each requires a solid foundation of technology, transportation, and orbital facilities.

It would not be good strategy, good science, or good policy for the U.S. to select a single initiative, then pursue it single-mindedly. The pursuit of a single initiative to the exclusion of all others results in leadership in only a limited range of space endeavor.

A strategy for the U.S. space program must be carefully selected to be consistent with our national aspirations and consistent with NASA's capabilities. It is not NASA's role to determine the strategy for the civilian space program. But it is NASA's role to lead the debate, to propose technically feasible options, and to make thoughtful recommendations.

It is in this spirit that we suggest the outline of one strategy – a strategy of evolution and natural progression. The strategy would begin by increasing our capabilities in transportation and technology – not as goals in themselves, but as the necessary means to achieve our goals in science and exploration. The most critical and immediate needs are related to advanced transportation systems to supplement and complement the Space Shuttle, and advanced technology to enable the bold missions of the next century. Until we can get people and cargo to and from orbit reliably and efficiently, our reach will exceed our grasp; until we begin the technologies proposed by Project Pathfinder, the realization of our aspirations will remain over a decade away.

The strategy emphasizes evolving our capabilities in low-Earth orbit, and using those capabilities to study our own world and explore others. With these capabilities, we would position ourselves to lead in characterizing and understanding planet Earth; we would also position ourselves to continue leading the way in human exploration.

According to the NASA Advisory Council's Task Force on Goals, "Recognized leadership absolutely requires the expansion of human life beyond the Earth, since human exploration is one of the most challenging and compelling displays of our spacefaring abilities."

We should explore the Moon for what it can tell us, and what it can give us – as a scientific laboratory and observing platform, as a research and technology test bed, and as a potential source of important resources. While exploring the Moon, we would learn to live and work on a hostile world beyond Earth. This should be done in an evolutionary manner, and on a time scale that is consistent with our developing capabilities.

The natural progression of human exploration then leads to Mars. There is no doubt that exploring, prospecting, and settling Mars should be the ultimate objectives of human exploration. But America should not rush headlong toward Mars; we should adopt a strategy to continue an orderly expansion outward from Earth.

The National Commission on Space urges 21st Century America "To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars." The United States space program needs to define a course to make this vision a reality.

EDUCATION

An informed public is essential to both the near-and long-term interests of the nation's civilian space program. The public needs an appropriate base of knowledge of scientific and technological issues in order to make educated decisions on space-related goals. Additionally, today's educational system must produce the high caliber scientists, engineers, technicians, social scientists, and humanists that will actually manage the large-scale space programs that are now envisioned. This means capturing the imaginations and interests of young people at an early stage in their educational careers and encouraging them to pursue studies that will prepare them to actively participate in the space program.

"Unless the youth of this nation are strongly motivated to seek their careers in the often difficult fields of science and technology – of which space is a particularly exciting and rewarding constituent – no amount of federal program emphasis can by itself sustain a long-term leadership role for the U.S. in civil space activities." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"As revealed in a recent national survey of student achievement, an estimated 90 percent of America's high school graduates may not be capable of accomplishing even the most routine high-technology tasks in the future. While up to 90 percent of high school graduates in other countries enjoy a proficiency in math and science, a mere 6 percent of U.S. graduates attain the same aptitudes. . . . This challenge exists at every level from elementary through graduate education." *Pioneering the Space Frontier*, 1986

"Thus, a strong educational system is an essential component of a vital science without which scientific progress would come to a rapid halt. It is most important to ensure that students are being broadly educated in concepts and skills which will be useful throughout their careers." *The Crisis in Space and Earth Science*, 1986

"The future of space biology and medicine will depend on the quality of the young people attracted to the field. NASA should expand its fellowship programs to encourage predoctoral and postdoctoral training at Universities, research institutes, and NASA research centers. Even in a period of reduced flight opportunities, there is exciting important research to be done in ground-based laboratories." *A Strategy for Space Biology and Medical Science*, 1987

Sally K. Ride, NASA Astronaut and chair of the NASA task force which prepared the report, Leadership and America's Future in Space. Currently, Director of the California Space Institute, University of California at San Diego.

Reproduced from Pioneering the Space Frontier: the report of the National Commission on Space. New York, Bantam Books, 1986. p. 2-22.

A PIONEERING MISSION FOR 21st-CENTURY AMERICA

To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars.

RATIONALE FOR EXPLORING AND SETTLING THE SOLAR SYSTEM

Our Vision: The Solar System as the Home of Humanity

The Solar System is our extended home. Five centuries after Columbus opened access to "The New World" we can initiate the settlement of worlds beyond our planet of birth. The promise of virgin lands and the opportunity to live in freedom brought our ancestors to the shores of North America. Now space technology has freed humankind to move outward from Earth as a species destined to expand to other worlds.

Our Purpose: Free Societies on New Worlds

The settlement of North America and other continents was a prelude to humanity's greater challenge: the space frontier. As we develop new lands of opportunity for ourselves and our descendants, we must carry with us the guarantees expressed in our Bill of Rights: to think, communicate, and live in freedom. We must stimulate individual initiative and free enterprise in space.

Our Ambition: Opening New Resources to Benefit Humanity

Historically, wealth has been created when the power of the human intellect combined abundant energy with rich material resources. Now America can create new wealth on the space frontier to benefit the entire human community by combining the energy of the Sun with materials left in space during the formation of the Solar System.

Our Method: Efficiency and Systematic Progression

In undertaking this great venture we must plan logically and build wisely. Each new step must be justified on its own merits and make possible additional steps. American investments on the space frontier should be sustained at a small but steady fraction of our national budget.

Our Hope: Increased World Cooperation

In his essay *Common Sense,* published in January of 1776, Tom Paine said of American independence, " 'Tis not the affair of a City, County, a Province, or a Kingdom; but of a Continent. . . . 'Tis not the concern of a day, a year, or an age; posterity are virtually involved in the contest, and will be more or less affected even to the end of time, by the proceedings now." Exploring the Universe is neither one nation's issue, nor relevant only to our time. Accordingly, America must work with other nations in a manner consistent with our Constitution, national security, and international agreements.

Our Aspiration: American Leadership on the Space Frontier

With America's pioneer heritage, technological preeminence, and economic strength, it is fitting that we should lead the people of this planet into space. Our leadership role should challenge the vision, talents, and energies of young and old alike, and inspire other nations to contribute their best talents to expand humanity's future.

Our Need: Balance and Common Sense

Settling North America required the sustained efforts of laborers and farmers, merchants and ministers, artisans and adventurers, scientists and seafarers. In the same way, our space program must combine with vigor and continuity the elements of scientific research, technological advance, the discovery and development of new resources in space, and the provision of essential institutions and systems to extend America's reach in science, industry, and the settlement of space.

Our Approach: The Critical Lead Role of Government

As formerly on the western frontier, now similarly on the space frontier, Government should support exploration and science, advance critical technologies, and provide the transportation systems and administration required to open broad access to new lands. The investment will again generate in value many times its cost to the benefit of all.

Our Resolve: To Go Forth "In Peace for All Mankind"

When the first Apollo astronauts stepped onto the Moon, they emplaced a plaque upon which were inscribed the words, "We came in peace for all mankind." As we move outward into the Solar System, we must remain true to our values as Americans: To go forward peacefully and to respect the integrity of planetary bodies and alien life forms, with equality of opportunity for all.

A NEW LONG-RANGE CIVILIAN SPACE PROGRAM

Program Thrusts

The National Commission on Space proposes a future-oriented civilian space agenda with three mutually-supportive thrusts:

- **Advancing our understanding of our planet, our Solar System, and the Universe;**
- **Exploring, prospecting, and settling the Solar System; and**
- **Stimulating space enterprises for the direct benefit of the people on Earth.**

We judge these three thrusts to be of comparable importance. They are described in Part I of our report: *Civilian Space Goals for 21st-Century America.*

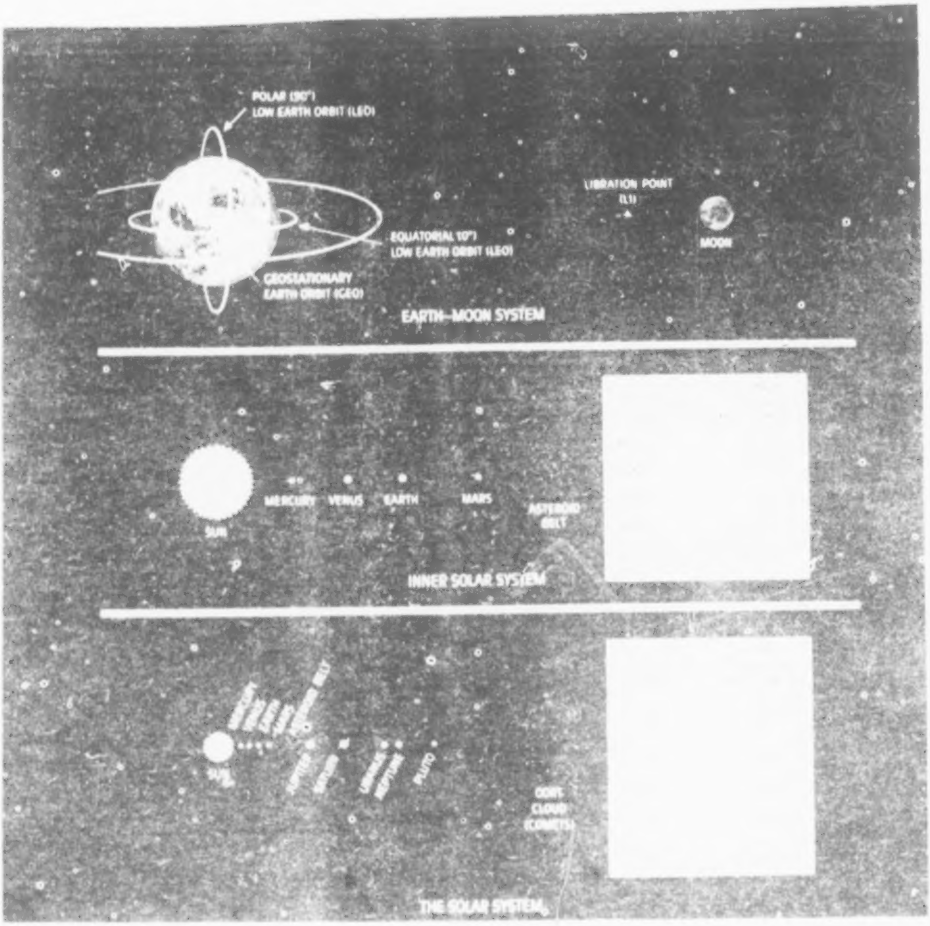
To accomplish them economically, the Nation must make a long-range commitment to two additional thrusts:

- **Advancing technology across a broad spectrum to assure timely availability of critical capabilities; and**
- **Creating and operating systems and institutions to provide low-cost access to the space frontier.**

These two thrusts are described in Part II of our report: *Low-Cost Access to the Solar System,* including *Building the Technology Base,* constructing a *Highway to Space,* and establishing a *Bridge between Worlds.*

A Logical Approach

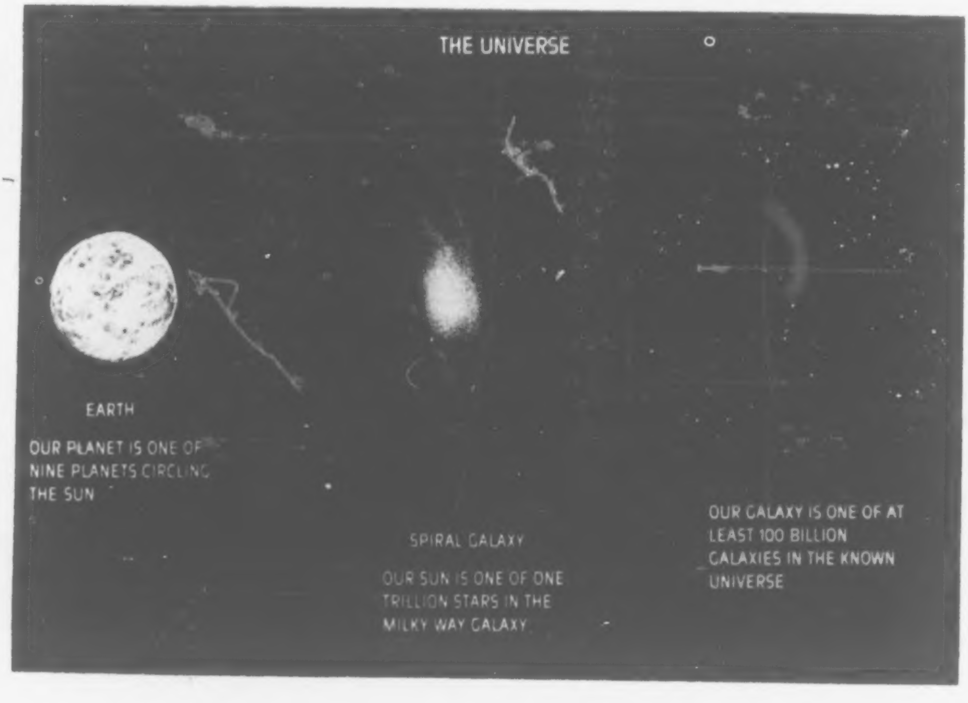
To meet the challenge of the space frontier, the Commission proposes a sustained step-by-step program to open the inner Solar System for exploration, basic and applied research, resource development, and human operations. This program will require a creative partnership of Government, industry, and academia of the type that has proved highly productive in previous



national enterprises. U.S. leadership will be based upon a reliable, affordable transportation system and a network of outposts in space. This infrastructure will allow us to extend scientific exploration and to begin the economic development of the vast region stretching from Earth orbit outward to the surface of our Moon, to Mars and its moons, and to accessible asteroids. We can achieve our recommended program most economically and with minimum risk through a systematic program structured in accordance with the inner Solar System's natural characteristics: energy, distance, signal delay time, and availability of resources. These characteristics lead to a natural progression for future space activities within the inner Solar System.

- **Low Earth orbits** are those just beyond Earth's atmosphere and are therefore the easiest to reach from Earth. They provide both our nearest orbital view of Earth and our nearest clear window for observation of the Universe. Freedom from strong gravitational effects allows experiments impossible on Earth and facilitates construction of large structures of low mass. In this region, our mother planet provides a sheltering skirt of magnetic field that protects us from the radiation produced by solar flares.
- **Geostationary orbit**, 22,300 miles above Earth's equator, is the orbit in which spacecraft match Earth's 24-hour rotation and hold fixed longitudes. This valuable real estate is a tenth of the distance to the Moon and is the locale of today's entire civil communications satellite industry.

- **Lunar distance** is 240,000 miles. The Moon is our nearest nonterrestrial source of abundant materials. The energy required to bring materials from the Moon to high Earth orbit is less than a twentieth of that needed to lift an equal mass from Earth to such an orbit. Round-trip communication time for a television image traveling at the speed of light to arrive from lunar distance and for a responding command signal from Earth can be as low as three seconds. This short time may allow practical teleoperation of remote machines on the Moon by people on Earth.
- **Mars and the asteroids** are the nearest resource-rich bodies beyond our Moon. Because they are on the order of 1,000 times as far away, voyages to them require many months. Even at the speed of light, round-trip communication with them involves times of 10 to 40 minutes, so robotic machines on these Solar System bodies must be "smarter" than those on the Moon. However, certain distant objects with valuable resources can be reached with low energy expenditure, including the Martian moons Phobos and Deimos and some asteroids.
- **Work sites and energy.** We gain access to useful materials when we land on a moon or planet, but pay a price in propellants to descend to those surfaces. There we also lose full-time solar energy, which is valuable for industrial processing, and lose microgravity, which is advantageous for building large space structures. Early industrial production in space may, therefore, be best achieved by transporting raw materials from the Moon to high orbit for processing and fabrication into finished products in robotic factories powered by continuous solar energy. As on Earth, the economics of mining, processing, transportation, fabrication, and point of utilization will determine the best locations for transportation hubs and industrial centers within the inner Solar System.


THE UNIVERSE
EARTH
OUR PLANET IS ONE OF NINE PLANETS CIRCLING THE SUN
SPIRAL GALAXY
OUR SUN IS ONE OF ONE TRILLION STARS IN THE MILKY WAY GALAXY
OUR GALAXY IS ONE OF AT LEAST 100 BILLION GALAXIES IN THE KNOWN UNIVERSE

Principal Recommendations

Consistent with our proposed five basic thrusts and the logical approach outlined above, the major parts of our report that follow include a number of specific recommendations.

Advancing Science

We recommend an aggressive space science program with three major objectives: (1) understanding the structure and evolution of the Universe, our Galaxy, our Solar System, and planet Earth, including the emergence and spread of life; (2) applying this understanding to forecast future phenomena of critical significance to humanity; and (3) using the environment of spaceflight and the tools of space technology to study the basic properties of matter and life. We have reviewed the current plans of U.S. science advisory groups for orderly progress toward these goals in the several disciplines of science. We endorse these plans, and note that an exciting opportunity exists to integrate the research results from previously separate disciplines. In order to foster this integrated approach to research on fundamental questions in science, the Commission recommends:

A sustained program to understand the evolution of the Universe, through astronomical facilities of increasing power, precision, and sophistication at locations in more distant Earth orbits and at eventual locations on the Moon.

A study of the evolution of the Solar System by using samples returned from selected planets, moons, asteroids, and comets. With returned samples, we can use all of our sophisticated laboratory technologies to perform the analyses. The results will also contribute significantly to the future discovery and utilization of space resources.

A global study of planet Earth using both ground- and space-based instruments. The goal of the study is in-depth understanding of the processes that shape our planet's interior, oceans, atmosphere, and polar ice caps, with particular emphasis on phenomena which affect, or are affected by, life, and the means to forecast, quantitatively, such phenomena.

A study of the Sun and the vast region it influences, using remote sensing from Earth as well as interplanetary probes. We must seek to understand the generation of energy deep in the Sun, its transformation into radiations that affect Earth and planets as well as life, and its interaction with solar and planetary magnetic fields. The processes involved occur throughout all space, so our understanding will be broadly applicable.

A continuing program to search for evidence that life exists—or has existed—beyond Earth, by studying other bodies of the Solar System, by searching for planets circling other stars, and by searching for signals broadcast by intelligent life elsewhere in the Galaxy.

Provision of state-of-the-art facilities for laboratory experiments on the ground and on the Space Station to increase the returns from the Nation's investment in space science, with particular attention to computer modeling, data access, advanced graphics, and artificial intelligence software.

New research into the effects of different gravity levels on humans and other biological systems, as well as on processes in physics and chemistry. The planned space program and the extension proposed here provide both the opportunity and necessity to resolve fundamental questions and to solve pacing problems that depend on gravity. Particularly needed are long-duration studies of the reactions of humans and plants to the microgravity of free space, the one-sixth gravity of the Moon, and the one-third gravity of Mars.

Exploring, Prospecting, and Settling the Solar System

In addition to basic scientific research, we propose specific applied-science investigations to discover, study, and learn to use for human benefit the resources on the space frontier. These materials have special value because they do not have to be lifted from Earth and carried over a long supply line. As a natural consequence of these investigations, the future will see growing numbers of people working at Earth orbital, lunar, and, eventually, Martian bases, initiating the settlement of vast reaches of the inner Solar System.

Living in space will be practical even though for long-term good health, people and the food crops that support them require atmosphere, water, sunlight, protection from radiation, and probably some gravity. Technological advances will permit all of these requirements to be met in free space; food, oxygen, and water can be recycled within an artificial biosphere, shielding from cosmic and solar flare radiation can be provided by lunar soil transported from the Moon with little energy, and artificial gravity can be provided by rotation. In the event of illness or accident, we can return people to Earth from lunar distance within a few days. Thus, the Earth-Moon region is favored for initial industrial production and for testing prototype spaceships and life-support equipment for later voyages to Mars and its moons.

To support these activities the Commission recommends:

Continuing robotic prospector missions, using the techniques of remote sensing and of on-site measurements to discover and characterize usable materials on our Moon, Mars and its moons, and accessible asteroids. A very high priority should be given to discovering any resources that may be frozen near the lunar poles, to determining the potential water and hydrocarbon resources on the surfaces of Phobos, Deimos, and near-surface layers of Mars, and to charting and analyzing all of the asteroids that pass close to Earth.

Missions to obtain samples from selected sites on our Moon, Mars and its moons, and the most accessible asteroids. When prospector missions have identified the presence of valuable chemical elements, sample return missions will be needed to bring back enough material to characterize the minerals and initiate industrial process development based on the physical and chemical properties of the samples.

Robotic and human exploration and surveying of substantial areas and special features of the Moon and Mars. This effort will begin on the Moon with automated roving vehicles tele-operated from Earth, and on Mars with vehicles having substantial artificial intelligence. Robots will be followed by the first astronaut crews operating from lunar and Martian outposts and bases.

Human outposts and bases in the inner Solar System. On the space frontier, habitations with closed-ecology life-support systems and reliable power plants will be needed to support work crews and, eventually, their families for long-duration work. Maintenance of good health for people working on science, exploration, and enterprise in distant communities, some of them at less than Earth-normal gravity, requires more knowledge and the development of dependable new systems. The development of long-duration habitations in space, based upon local resources, is essential to the support of activities in all three of our primary areas: science, exploration, and enterprise.

Space Enterprise

Our proposals span the range from involving private enterprise more heavily in post-shuttle space transportation to the support of major new industries. We propose that NASA should have a role in encouraging new space enterprises through technological development and demonstration analogous to its traditional successful support of the private sector in aeronautical research. It is imperative that the private sector be much more heavily involved in defining the nature and specifications of future launch vehicles. This will help ensure the adoption of commercial practices that will reduce operating costs and make it possible to transfer operation of these vehicles to the private sector. Future vehicles for cargo and passenger transport should be designed to be readily operable by the private sector after development is complete and routine operation is reached. To accomplish this the Commission recommends: **That wherever possible the private sector be given the task of providing specified services or products in space, and be free to determine the most cost-effective ways to satisfy those requirements, consistent with evolving Federal regulations.** We also recommend: **That NASA initiate research and development now on systems and processes for application beyond low Earth orbit.**

These systems should include tele-operated machines to repair and refuel satellites in high orbit, and the machines of robotic lunar pilot plants. Lunar resource utilization will depend on automated and tele-operated machines which are reliable and easy to use. This equipment must be developed through the pilot-plant stage for robotic plants capable of transforming lunar and other non-terrestrial raw materials into propellants, shielding materials, structural elements, and industrial raw materials.

Building the Technology Base

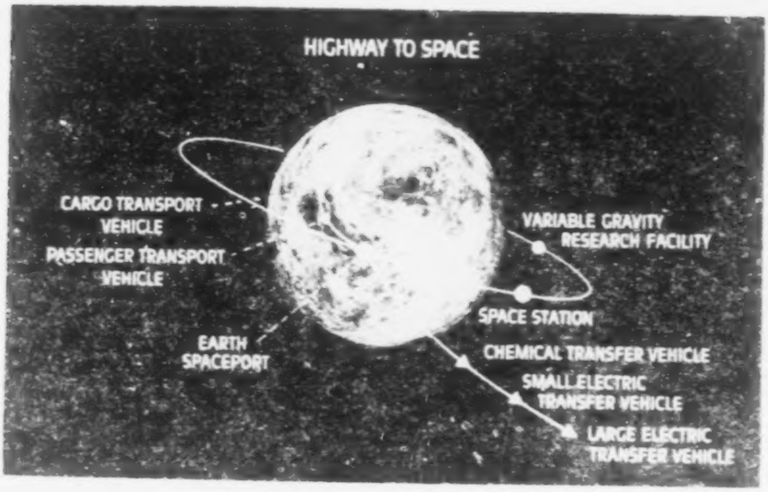
The United States must substantially increase its investment in its space technology base. We recommend: **A threefold growth in NASA's base technology budget** to increase this item from two percent to six percent of NASA's total budget. This growth will permit the necessary acceleration of work in many critical technical fields from space propulsion and robotic construction to high-performance materials, artificial intelligence, and the processing of non-terrestrial materials. We also recommend: **Special emphasis on intelligent autonomous systems.** Cargo trips beyond lunar distance will be made by unpiloted vehicles, the earliest roving vehicles on the Martian surface will be unpiloted, and processing plants for propellants from the materials on asteroids, Phobos, or Mars will run unattended. To support these complex, automated, remote operations, a new generation of robust, fault-tolerant, pattern-recognizing automata is needed. They must employ new computers, sensors, and diagnostic and maintenance equipment that can avoid accidents and repair failures. These systems must be capable of taking the same common-sense corrective actions that a human operator would take. These developments by NASA should also have broad application to 21st-century U.S. industry.

We recommend demonstration projects in seven critical technologies:

- **Flight research on aerospace plane propulsion and aerodynamics;**
- **Advanced rocket vehicles;**
- **Aerobraking for orbital transfer;**

- **Long-duration closed-ecosystems (including water, air, and food);**
- **Electric launch and propulsion systems;**
- **Nuclear-electric space power; and**
- **Space tethers and artificial gravity.**

These base technology and demonstration programs are discussed in detail in Part II of our report: *Building the Technology Base.*


HIGHWAY TO SPACE
CARGO TRANSPORT VEHICLE
PASSENGER TRANSPORT VEHICLE
EARTH SPACEPORT
VARIABLE GRAVITY RESEARCH FACILITY
SPACE STATION
CHEMICAL TRANSFER VEHICLE
SMALL ELECTRIC TRANSFER VEHICLE
LARGE ELECTRIC TRANSFER VEHICLE

Highway to Space

The two most significant contributions the U.S. Government can make to opening the space frontier are to ensure continuity of launch services and to reduce drastically transportation costs within the inner Solar System. The shuttle fleet will become obsolescent by the turn of the century. Reliable, economical launch vehicles will be needed to provide flexible, routine access to orbit for cargo and passengers at reduced costs. A complementary system is needed for low-cost transport from low Earth orbit to geostationary orbit and lunar distance. To reduce space operation costs as soon as possible, the Commission recommends that: **Three major space transport needs be met in the next 15 years; the three major transport systems requirements are:**

- Cargo transport to low Earth orbit;

- Passenger transport to and from low Earth orbit; and
- Round-trip transfer beyond low Earth orbit.

For cargo transport, we propose that a new vehicle be put into operation by the year 2000 with a goal of achieving operation costs of $200 per pound delivered into orbit.

For passenger transport, we see two competing developments for the follow-on to the shuttle: an advanced reusable rocket vehicle or an airbreathing aerospace plane. These piloted vehicles could carry both passengers and compact cargo. Accordingly, we propose an intensive technology base program for the next five years to provide critical engineering data on both systems so the Nation can make a sound selection by 1992. Key technologies include computational fluid dynamics, dual-fuel rocket propulsion, supersonic combustion ramjet engines, high-performance materials, structures, aerodynamics, thermal shielding, and launch automation.

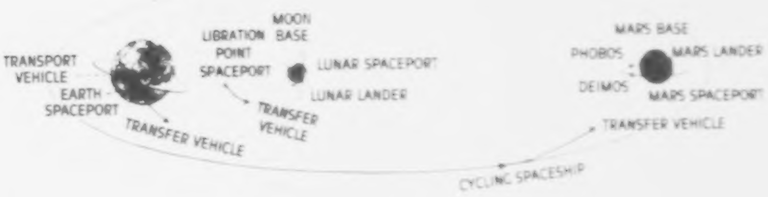
The airbreathing hypersonic propulsion has broad potential for a number of 21st-century applications, including intercontinental passenger transport, low-cost orbital transport, and a wide range of defense missions. **The Commission therefore supports a major national commitment to achieve early flight research with an experimental aerospace plane.** We also believe that in the next century the passenger transport system should be developed and operated privately for routine non-military operation between Earth and low Earth orbit.

For destinations beyond Earth orbit, a new transfer vehicle will be required. In the coming era of fully reusable Earth-to-orbit vehicles, the needs of Government and industry for the reliable emplacement of expensive satellites beyond low Earth orbit will require new space-based "workhorse" vehicles designed for flexibility through modular systems. Basic components should be capable of being ganged, or provided with extra tankage, for higher energy missions. They should be capable of transporting both cargo and people, be reusable, employ aerobraking, and be adapted to on-orbit servicing, maintenance, test, and repair. A transfer vehicle will be required to lift large payloads to geostationary orbit, to move payloads and crews to lunar orbit, to land payloads on the lunar surface, and to travel beyond the Earth-Moon system. Its Space Station base may be a critical pacing item. This vehicle should be designed for return to a low Earth orbit spaceport using aerobraking. The Commission recommends that: **The U.S. Space Station program be kept on schedule for an operational capability by 1994, without a crippling and expensive "stretch-out," and a space-based robotic transfer vehicle be developed to initiate a Bridge between Worlds.**

Bridge Between Worlds

Many of the systems needed for reaching outward to the planet Mars will be proven in the course of work in the Earth-Moon region. Others listed here are special to operations conducted at distances so remote from Earth that tele-operation and close mission support are not possible. To build the 21st-century Bridge Between Worlds that will open the Solar System, the Commission recommends:

BRIDGE BETWEEN WORLDS



Developing reliable high-performance electric propulsion systems, including mass drivers and ion propulsion able to operate throughout the entire Solar System. Candidate technologies should be pursued vigorously to ensure that they will be ready when needed. Mass-driver reaction engines would be able to use as propellants raw materials from Earth's Moon, Phobos, Deimos, or asteroids. They, and other electric thrusters, would be able to run on solar or nuclear electric power.

Developing fully self-sustaining biospheres independent of Earth. For routine operation beyond the Moon, it is essential that life support be maintained using on-site materials, without reliance on long supply lines.

Establishing initial outposts and bases on the Moon and Mars that combine objectives, including life support, science, exploration, prospecting, resource development, material processing, automated rocket fuel production, and robotic fabrication. Long-term exponential growth into eventual permanent settlements should be the overarching goal.

An Economical, Phased Approach

In considering the financial resources required to carry out our recommended agenda and future civilian space budget levels needed to meet our goals, the Commission considered the potential growth of the U.S. economy from a number of perspectives, as discussed in Part IV of our report: *21st-Century America*. Based on what we believe to be realistic growth assumptions, we are confident that the long-range agenda we recommend can be carried out within reasonable civilian space budgets. Figure 1 outlines our phased approach to achieve low-cost access to the Solar System. The Highway to Space starts with economical new cargo and passenger transport vehicles, adding a transfer vehicle for destinations beyond low Earth orbit. These three systems would become operational in conjunction with an orbital spaceport within 15 years. In the following 5 years, the Bridge Between Worlds would support initial robotic lunar surface operations, followed by a permanent outpost to support astronaut operations. In 10 more years the space bridge would be extended out to Mars for detailed robotic exploration followed by a Mars outpost for human activity. To achieve this the Commission recommends that: **The phased space transportation network outlined in Figure 1 be developed and placed in operation.** It starts with simple components, but evolves over time into a system of spaceports, bases, and connecting transportation systems that will open the space frontier for large-scale exploration, science, and the initiation of economic development. Resources will be utilized where they are found, to minimize the need for resources transported from Earth. This inner Solar System network will ensure continuing American leadership in space in the next century.

Implementing the Program

The hallmarks of this program are the technological advances needed for major cost-reduction and capability extension. Figure 2 depicts the growth of the U.S. Gross National Product (GNP) for the past 25 years, and projects it forward for 50 years at an annual growth rate of 2.4 percent, as discussed in Part IV of our report. The estimated annual costs of the space advances that are outlined in Figure 1 are shown as an extension of the U.S. civilian space budgets of the past quarter century, assuming continuing international and commercial contributions to the program. Note that the percentage of the U.S. GNP invested in opening the space frontier would remain below one-half of the percentage spent on space during the peak Apollo years. We believe that these estimated levels of expenditure will prove to be affordable and reasonable in view of America's projected economic growth and the increasing significance of space development in the next century. We recognize, however, that this long-range program is a new challenge to the management of our Nation's space enterprise. For this reason we recommend that: **The Administration and the Congress continue to work together to set a new long-range direction and pace for America's civilian space program.** We sincerely hope that this Commission's report will contribute to a reexamination of and fresh approach to America's future in space. We see the need for longer-range vision, greater leadership, and more effective management of critical technological, financial, and institu-

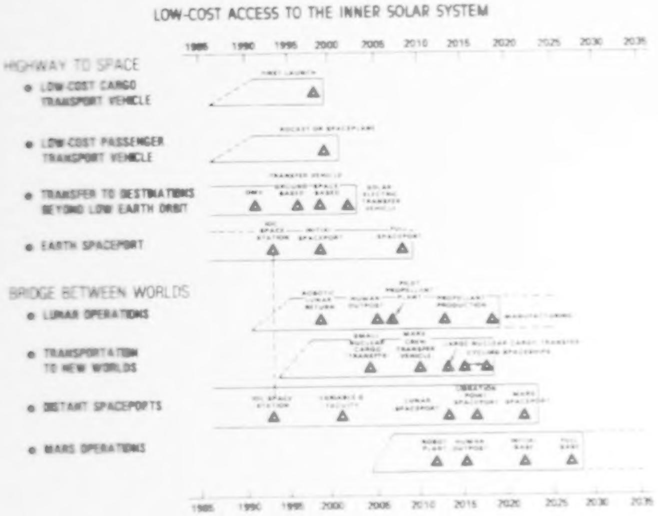


FIGURE 1

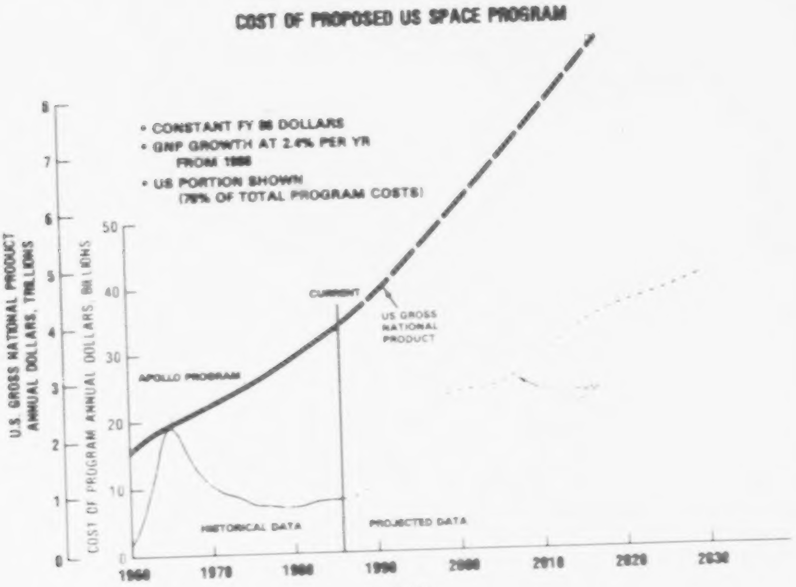


FIGURE 2

tional resources. This will also facilitate greater public understanding and participation, and more rewarding international partnerships.

The Commission's report has value only to the extent that its recommended space goals for 21st-century America are adopted and acted upon. If the decision is made to proceed along these lines, the detailed review, planning, and budget preparation should be carried out by NASA in consultation with NOAA and other agencies. The Commission therefore recommends that: **The President and the Congress direct the Administrator of NASA to review the Commission's findings and proposed space agenda, and by December 31, 1986, to recommend a long-range implementation plan, including a specific agenda for the next five years.**

Improved Oversight Through a Longer-Range Perspective

The President's Blue Ribbon Commission on Defense Management has recommended a number of reforms in defense systems acquisition that parallel our conclusions on improving the management of America's civilian space program. We recommend three specific changes similar to those proposed by the Packard Panel:

Twenty-year civilian space program and five-year budget planning to establish long-range goals and budgets for review and decision by the Administration and the Congress;

Multi-year procurements to replace year-by-year funding, with firm decisions that eliminate annual changes which have proven very costly to NASA and its contractors;

Two-year overall approval of civilian space budgets by the Office of Management and Budget and the appropriate Congressional committees to replace annual line-by-line auditing.

International Cooperation and Competition

This is discussed in detail in the section *International Cooperation and Competition*. In proposing continuing American leadership on the space frontier, the Commission recommends that: **Vigorous steps be taken to attract other nations to work in partnership with us.** We must mobilize this planet's most creative minds to help us achieve our challenging goals. All of humankind will benefit from cooperation on the space frontier.

Twelve Technological Milestones in Space

The program we propose sets the stage for exciting achievements in pioneering the space frontier. A dozen challenging technological milestones would mark our progress:

- **Initial operation of a permanent Space Station;**
- **Initial operation of dramatically lower cost transport vehicles to and from low Earth orbit for cargo and passengers;**
- **Addition of modular transfer vehicles capable of moving cargoes and people from low Earth orbit to any destination in the inner Solar System;**

- **A spaceport in low Earth orbit;**
- **Operation of an initial lunar outpost and pilot production of rocket propellant;**
- **Initial operation of a nuclear electric vehicle for high-energy missions to the outer planets;**
- **First shipment of shielding mass from the Moon;**
- **Deployment of a Spaceport in lunar orbit to support expanding human operations on the Moon;**
- **Initial operation of an Earth-Mars transportation system for robotic precursor missions to Mars;**
- **First flight of a cycling spaceship to open continuing passenger transport between Earth orbit and Mars orbit;**
- **Human exploration and prospecting from astronaut outposts on Phobos, Deimos, and Mars; and**
- **Start-up of the first Martian resource development base to provide oxygen, water, food, construction materials, and rocket propellants.**

With these giant steps, America will lead a dynamic movement of humankind to new worlds in the 21st century.

BENEFITS

The new space program we propose for 21st-century America will return tangible benefits in three forms:

- By **"pulling-through" advances in science and technology** of critical importance to the Nation's future economic strength and national security;
- By **providing direct economic returns** from new space-based enterprises that capitalize upon broad, low-cost access to space; and
- By **opening new worlds on the space frontier**, with vast resources that can free humanity's aspirations from the limitations of our small planet of birth.

"Pulling-Through" Technology

As we learned in World War II, government-academia-industry teams mobilized to accelerate advances in science and technology can build the foundations for new growth industries even though the original objectives were narrowly focused on military requirements. Wartime breakthroughs in jet propulsion, antibiotics, synthetic rubber, oil pipelines, nuclear energy, microwave radar, liquid-fueled rockets, radio guidance, electronic computers, and other systems led to America's high growth industries of the 1960s and 1970s in global jet transport, pharmaceuticals, synthetic materials, nuclear electric power, microwave communication, electronic computers, and many others. Technological advances from later Government programs made possible today's weather satellites, global marine communications, and the multibillion-dollar communications satellite industry that links together more than 100 nations on every continent. The space program has also initiated additional fledgling industries in remote sensing, direct broadcast, and navigation that appear likely to become future growth industries.

The program we recommend will motivate people, provide new standards of excellence, and stimulate many fields of science and technology, including those that we believe will be most critical to the economic growth of 21st century America. Specific examples include artificial intelligence, robotics, tele-operation, process automation, hypersonic flight, low-cost global and orbital transport, optical communication and data processing systems, ultra-high-strength and high-temperature materials, supercomputers, wireless power transmission, pollution-free vehicles (electric and hydrogen-oxygen fueled), orbital antenna farms, closed-ecology biosphere operation (which could revolutionize intensive agriculture)—and myriad others.

Return from Investment in Technology

In the last 50 years, Government-sponsored research and development created "enabling technologies" in aeronautics and in communications satellites. The needs of governmental agencies and of the public for new services attracted private capital to apply those technologies, leading to great new global industries. In the airmail contracts of the 1920s and 1930s, a public need for service played an additional vital role through the guarantee of markets to assist the growth of fledgling airline companies.

During the next 20 years, the Space Station may spark new industries by serving as a space laboratory for academic and industrial researchers. New processes of economic significance can be expected from applied materials and processes research in microgravity. Other new economic opportunities may come through laboratory environments isolated from Earth's biosphere, through the orbital global perspective for communications, navigation and observation of Earth, and through increased public access to space. Obtaining a return from new processes will require private investment in orbiting industrial parks established to provide common services to entrepreneurial companies carrying out independent operations in orbit.

New Space-Based Enterprises

In order to attract substantial private capital to build new space industries, the Government should create as early as possible the least expensive enabling technologies sufficient to open the energy and material resources of space. The private sector, especially its entrepreneurial part, is well situated and motivated to find the most rapid way to serve new markets. Companies are driven by the need to obtain returns on their investments, and financing is extremely difficult to obtain for high-risk ventures unless the returns occur quickly. This forces speed and concentration on specific opportunities.

We believe there will be such opportunities when the Highway to Space is extended via the Bridge between Worlds to high orbit and the Moon. The first products based upon materials found on the Moon include oxygen for rocket propellants and raw mass for shielding piloted orbital stations against cosmic and solar flare radiation. When the Highway to Space is extended to the Moon, an opportunity will be created to bring those products to Earth orbit at far less cost in energy than lifting them from Earth.

The transfer vehicle, capable of round-trip journeys from low orbit to the Moon and of piloted or remotely piloted operation, to which we give high priority in our recommendations, is the enabling technology needed to emplace experimental plants which could be operated by the private sector. When that second link in our space transport system is completed, the event will compare in significance to the driving of the Golden Spike in Utah more than a century ago that marked completion of the transcontinental railroad.

Private companies, driven by their need for rapid return on investment, could make use of the transfer vehicle to emplace economical pilot plants to provide lunar-derived shielding and oxygen. These plants would make strong use of robotics technology and would probably be tele-operated remotely from Earth. They would serve a highly valuable reinforcing role to the long-term space program by demonstrating soon the practical value of space resources. The Government could serve a vital role and reduce its own costs for space operations by committing to buy shielding and oxygen in Earth orbit.

We cannot foresee the ingenuity that companies, established or entrepreneurial, will bring to the building of new industries in the 21st century based upon the Highway to Space. Nor can we know the individuals whose names will rank with Douglas, Boeing, Sikorsky, and the other pioneers of the aeronautical industry. But looking back for analogies, we know that one of America's greatest heroes, Charles Lindbergh, practiced the skills of piloting in heavy weather, prior to his Atlantic crossing, by flying the U.S. mail.

New Worlds on the Space Frontier

The immediate benefits from advances in science and technology and from new economic enterprises in space are sufficient in our view to justify the civilian space agenda we propose. However, we believe that the longer-term benefits from the settling of new worlds and the economic development of the inner Solar System will prove even more rewarding to humanity. These returns are difficult to quantify. What was the true value of developing and settling North and South America, Australia, and New Zealand? Today more people speak English, Spanish, and Portuguese in the New World than in Europe, and they have built economies surpassing those of Europe. But the contributions to humanity from Columbus' "New World" are surely far beyond its material returns, impressive as they are. We believe that in removing terrestrial limits to human aspirations, the execution of our proposed space agenda for 21st-century America will prove of incalculable value to planet Earth and to the future of our species.

LOOKING FIFTY YEARS INTO THE FUTURE

The year is 1935. Pan American Airways is inaugurating trans-Pacific service, with additional flying boats on order to open trans-Atlantic service in 1939. The last Pony Express rider turns over his mail pouch to a young biplane pilot while newsreel cameras grind. Almost nobody expects to fly the Atlantic—that's for daredevils like Lindbergh—but half a million people per year cross in ocean liners. Washington's chief concern is the Federal Deficit: $30 billion in revenues versus $50 billion in outlays (1985 dollars).

The year is 1985. Could we explain to a visitor from 1935 that more than 25 million people now fly the Atlantic every year? That 16 years ago astronauts flew at 24,790 miles per hour to the Moon? That communication satellites are flashing color television signals around the world? That a spacecraft has transmitted pictures and data from Uranus across 1.8 billion miles, and is now flying on to Neptune? That supercomputers are being used to design next-generation spacecraft that will drastically reduce the cost of space travel? Washington's grappling with the Federal Budget deficit might sound familiar, but 50 years of cumulative technological advance would be beyond comprehension.

What will 2035 be like? The National Commission on Space has been charged by the Congress and the President to look into the future to propose civilian space goals for 21st-century America. It is as challenging for us today to envision the advanced world of 2035 as it was to foresee today's world back in 1935. Even the most visionary science fiction writer then failed to foresee the scale of the resources that would be needed to initiate the Space Age, and that no one imagined these would become available within 25 years. Looking to the future, we are confident that the next century will see pioneering men and women from many nations working and living throughout the inner Solar System. Space travel will be as safe and inexpensive for our grandchildren as jet travel is for us. Our vision and our recommendations are outlined in this report. **Through vigorous leadership on the space frontier, America can make this happen.**

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THE NASA PROGRAM IN THE 1990s AND BEYOND

PREFACE

The United States space program stands at a crossroads. The momentum of the National Aeronautics and Space Administration (NASA) program over the last 20 years has brought NASA to a point where new activities will require substantial increases in the agency's budget. Critics of the NASA program have called for even more ambitious goals, most prominently an expansion of manned space flight to the Moon or Mars. Fiscal concerns, however, may limit even the more modest set of activities envisioned by NASA. This special study, requested by the Senate Committee on Commerce, Science, and Transportation, examines the broad options for the U.S. space program in the 1990s. In keeping with the mandate of the Congressional Budget Office (CBO) to provide objective nonpartisan analysis, the report makes no recommendations.

David H. Moore, of CBO's Natural Resources and Commerce Division, prepared the report under the supervision of Everett M. Ehrlich. Frances M. Lussier of CBO's National Security Division and Michael Sieverts of CBO's Budget Analysis Division provided valuable comments and assistance. Many outside reviewers made useful comments and criticisms. Amanda Balestrieri edited the manuscript. Margaret Cromartie prepared early drafts of the report, and Kathryn Quattrone prepared the final draft for publication.

James L. Blum
Acting Director

May 1988

The Congress of the United States
Congresssional Budget Office

Reproduced from The NASA Program in the 1990s and Beyond, by David H. Moore. Washington, U.S. Congressional Budget Office, 1988. p. ix-xxii, 1-13, 45-82.

NOTES

All costs are expressed in 1988 dollars of budget authority, unless otherwise noted.

All years are fiscal years, except when applied to launch schedules.

SUMMARY

The Administration's 1989 budget request for the National Aeronautics and Space Administration (NASA)--including $6 billion (in current dollars) for the space station over the next three years--raises vital issues regarding the future of the NASA program. On a current dollar basis, the fiscal year 1989 proposal is 27 percent higher than the $9 billion appropriated in 1988. If NASA is to carry out the program it has envisioned (referred to as the "core program" in this study), then additional increases in funding will be required through the remainder of the century. To extend and exploit the technology and infrastructure created by NASA since the conclusion of the Apollo program in the early 1970s, the annual NASA budget under the core program would rise to $14.4 billion (1988 dollars) by 1993 and $16.4 billion (1988 dollars) by 2000.

The core program lies between two extremes that clearly illustrate the difficult choices involved in setting future U.S. space policy. At one end of the spectrum, new and ambitious initiatives beyond the core program, such as a lunar outpost or a manned expedition to Mars at the turn of the century, could more than triple NASA's current real budget by 2000. At the other end of the spectrum, if NASA were to limit its future spending to its current real level, it would be forced either to stretch out into the next century its planned space station and the other projects in the core program, or to adopt a less ambitious set of goals that de-emphasize manned space flight activities in favor of unmanned missions. Holding the NASA budget to its current real level would therefore limit the international leadership of the United States in space activities. This, in fact, is the difficult choice facing the Congress: whether to increase dramatically the commitment of the United States to preeminence in space exploration or to adapt the U.S. space program to a limited budget.

EVOLUTION OF NASA's CORE PROGRAM

After the Apollo mission to the Moon was completed in 1972, NASA embarked on a long-term project to build a reusable transportation system, space platforms (most notably a permanently manned space station), and a space-based data and communications network. These long-term plans provide the starting point for the Congressional Budget Office (CBO) estimate of the NASA core program presented in this study. The justification for these major investments was their promise for the future rather than their immediate contributions to the nation's accomplishment in space. They were to provide higher quality and more cost-effective science, exploration, and commerce from the 1980s to the end of the century.

Despite the repercussions of the explosion of the Challenger orbiter in January 1986, the course set in the 1970s and 1980s remains the agency's plan. But many aspects of this core program represent departures from past NASA efforts--notably, the scale of the projects, the interdependence among the different parts of the core program, and the significant annual expenditures necessary to operate facilities, such as the shuttle system, after they are built.

The shuttle system, with its three airplane-like orbiters and supporting facilities, is the best example of these trends in the NASA program. In 1970 and 1980, the shuttle was the largest item in the NASA budget. Even in 1988, a year when the shuttle did not fly, the program consumed $3.2 billion. This amount represents a third of NASA's budget and does not include the shuttle's share of federal employees and program support carried in NASA's $1.7 billion research and program management budget. But since virtually every part of the NASA program depends on the shuttle, these expenditures must be made. The degree of interdependence within the NASA program will rise in the 1990s as space science and applications come to rely not only on the shuttle system and NASA's Earth orbit and deep space tracking networks, but also on the manned and unmanned space platforms planned for development in the space station program. This interdependence offers better, and ultimately more cost-effective, space activity. But it also exposes final missions to the physical, fiscal, and technical problems in the infrastructure on which they depend.

The Block One starter space station in the core program should cost about $19 billion in 1987 through 1996 (including operations), but, as with the shuttle, its effects on the budget will reach far beyond this initial expense. Once constructed, it could cost about $1.0 billion to $1.5 billion annually to operate. Moreover, a large part of the space station's value lies in making other space projects more productive (for example, by servicing satellites, providing an orbiting laboratory, or prepositioning materials for a high-orbit "spaceport" or a lunar base). If these other projects are not funded, the value of the space station is significantly reduced. Committing resources to the space station, therefore, may lead to even greater long-term NASA spending.

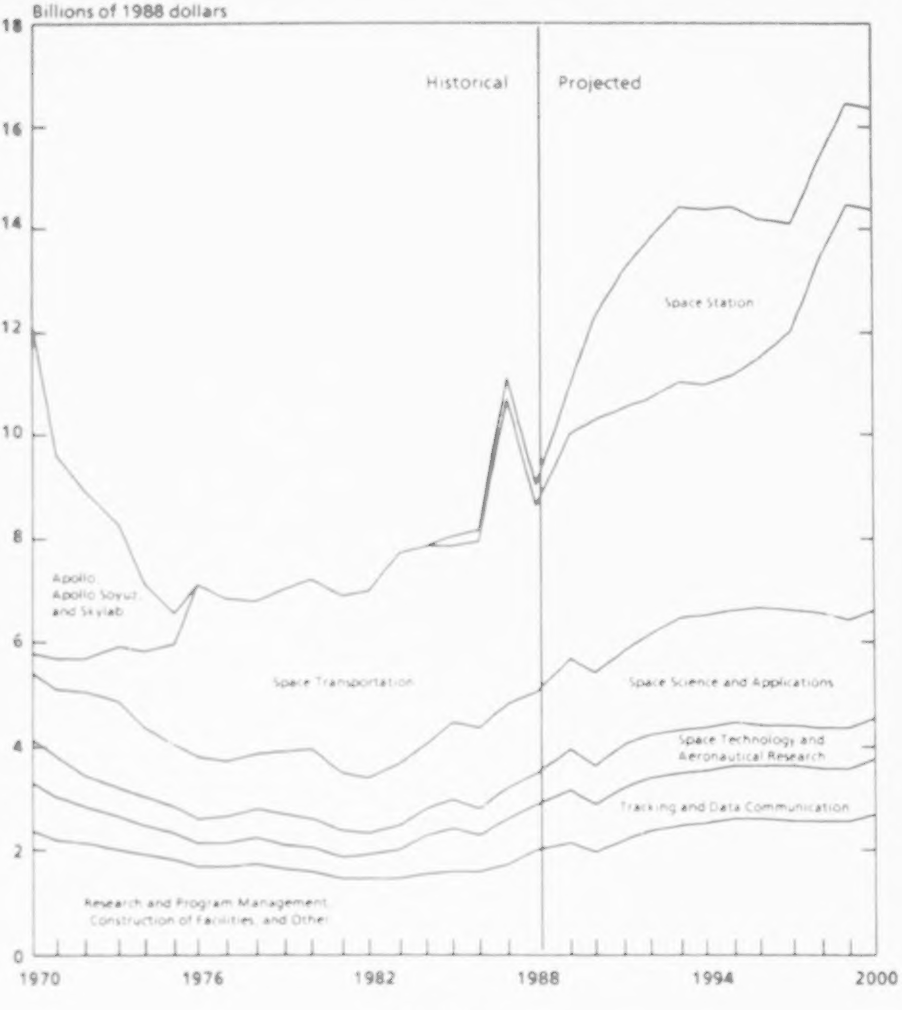
THE NASA CORE PROGRAM FOR THE 1990s

NASA's activities through the 1990s will be dominated by continuing development of its space infrastructure, operating the space transportation system, and moving forward to a new group of science missions that take advantage of the infrastructure in low Earth orbit. Summary Figure 1 presents the CBO estimate of the annual funding requirements for the NASA core program through the year 2000. It shows that the activities included in the core program could require NASA's annual budget to grow from $9.0 billion in 1988 to $14.4 billion by 1993, and to $16.4 billion by 2000.

Spacecraft developed in the 1980s, but grounded by the loss of the Challenger and the subsequent two and one-half year hiatus in shuttle flights, will be launched in 1989 and during the early 1990s. These missions include the Hubble Space Telescope, a series of smaller physics and astronomy satellites, the Galileo probe to Jupiter, experiments in processing materials on the shuttle, the Advanced Communication Technology Satellite, and various Earth and environmental observation missions, including the Upper Atmospheric Research Satellite. Many of these missions will test the ability of the infrastructure investments of the past two decades to deliver high-quality, cost-effective science.

Space transportation and the space station program are the major investment activities NASA proposes for the 1990s. Transportation

Summary Figure 1.
NASA Budget: Historical and Projected (the "Core Program")



SOURCES: Historical data, NASA budget plans as presented in *NASA Budget Estimates* for various years, and Congressional Budget Office projections.

investment and development averages $2.5 billion annually from 1989 through 2000, and includes major improvements in the current shuttle system (such as the Advanced Solid Rocket Motor), replacement orbiters to be procured during the 1990s, a family of in-space transportation vehicles (the Orbital Maneuvering and Orbital Transfer vehicles), and a replacement for the shuttle system to come into service sometime after 2000. The space station program--including the manned laboratory modules, an unmanned polar platform in a polar orbit, an emergency escape vehicle, and operations--will require $3.0 billion to $3.5 billion annually from 1992 through 1995.

Operating the current shuttle system, conventional rocket services, and a planned unmanned cargo carrier using the shuttle system's propulsion system (the Shuttle C) would cost as much as $3.1 billion annually by 1996, when operations of the Shuttle C are intended to begin. Operating the space station might cost as much as $1.5 billion annually beginning in 1999. Operating and maintaining the tracking and data network for low Earth orbit and deep space would cost an additional $1 billion annually, with the space shuttle, the space station polar platform, and manned laboratory modules as primary users.

Funding for space science and applications in the core program rises from the 1988 level of $1.5 billion to $2.2 billion by 1995. This funding supports the development of planned future missions in physics and astronomy, planetary exploration, and environmental and Earth observation; it also supports processing materials and life science programs related to the space station.

The physics and astronomy program is the largest single area of activity in space science and applications. It includes the Advanced X-Ray Astronomy Facility (proposed as a new start in the Administration's fiscal year 1989 budget request) in the early 1990s and the Space Infrared Telescope Facility later in the decade. Operating these two "Great Observatories" and their two already developed companions, the Hubble Space Telescope and the Gamma Ray Observatory, could require more than $0.2 billion annually by 2000. New planetary missions include the Comet Rendezvous/Asteroid Flyby and a probe to Saturn. The Earth Observation System would provide an integrated system to monitor and analyze natural and human influences on the Earth and its environment.

NASA's space research and technology program explores propulsion, supporting human activity in space, and automated systems and sensors--activities that are the foundation for all NASA space projects. The core program includes funding in this area of $0.4 billion annually. Developing large systems such as the shuttle and the space station pushes technology forward in these areas, but only as far as required to complete the project at hand. Unconstrained research is necessary to define the possibilities for future missions and to permit informed choices about these missions based on realistic forecasts of costs, schedules, and available technology.

Finally, the core program includes an annual average from 1989 through 2000 of $2.3 billion for research and program management and construction of facilities. Research and program management is by far the largest item and reflects the upward trend in the rest of the NASA program. Other NASA activities, such as safety and quality assurance, use of technology, and commercial programs, are projected forward at constant dollar levels over the 1990s.

This core program carries with it technical and cost uncertainties. Transportation costs may be reduced if efficiencies not previously realized are achieved in operating the shuttle system, or if unforeseen revenues are received from the private sector or other parts of the federal government. But cost overruns in major development efforts such as the space station, shuttle improvements, or large space science projects will affect not only these projects, but also the projects to which they are related. The additional costs inflicted on all NASA programs by the grounding of the shuttle system since the Challenger accident furnish an example of these effects.

ALTERNATIVES TO THE CORE PROGRAM

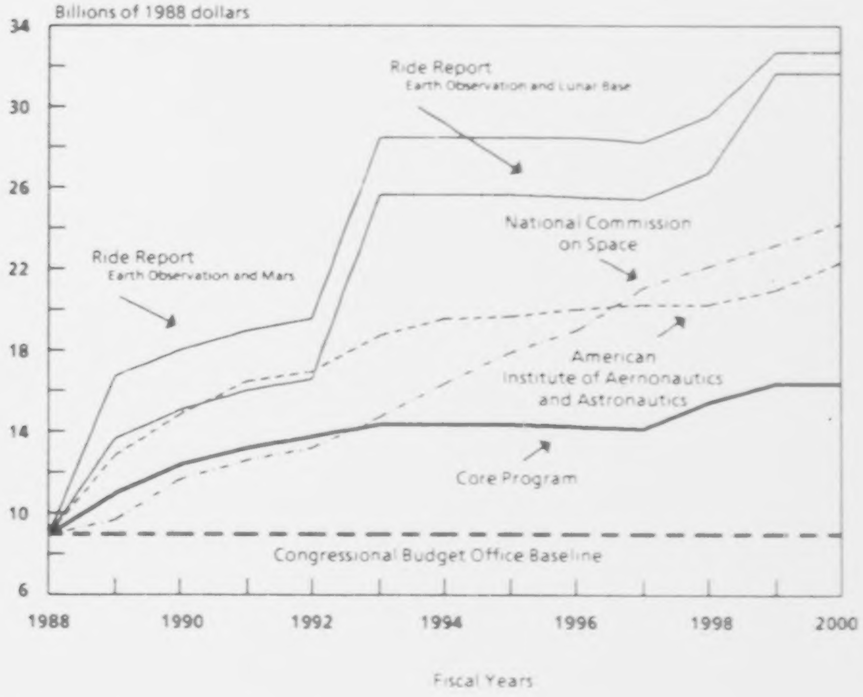
Two broad alternatives to the core program are open to the Congress:

- Mandate more ambitious goals than the core program and dedicate even more of the nation's resources to the civilian space program than those required by the core program, perhaps $30 billion annually by 2000; or

- o **Maintain NASA spending at the current level and stretch out or dramatically restructure the civilian space program, primarily by de-emphasizing manned space activities.**

Summary Figure 2 presents CBO's estimates of the NASA annual budget required by the core program and alternatives to it. Summary Box 1 compares the status of the U.S. space program during the 1990s under the broad options of the NASA core program, the new initiatives, and the budget-constrained programs as they relate to infrastructure, space science, applications and exploration, and research and technology.

Summary Figure 2.
NASA Budget Options, 1988-2000



SOURCE: Congressional Budget Office estimates.

SUMMARY BOX I
ALTERNATIVE NASA PROGRAMS FOR THE 1990s

The core program and alternatives to it differ in three ways: first, in the transportation, on-orbit facilities, and tracking and data communications *infrastructure* they would operate or develop; second, in the *space science, applications, and exploration* under way to exploit the capability of the available infrastructure; and, third, in the future missions toward which their *research and technology* bases are directed.

THE CORE PROGRAM

Infrastructure, which enables man's presence in space, is a central feature of the core program. The shuttle system would fly 8 to 14 times a year, and would be augmented by traditional rocket services, providing the equivalent of two and one-half additional shuttle flights annually. The unmanned cargo carrier, Shuttle C, would be launched twice a year by 1996, with the potential to carry the equivalent of two manned orbiter flights on each flight. The first generation of in-space transportation--the orbital maneuvering and space transfer vehicles--would be developed by the late 1990s. A new manned transportation system would be developed to replace the shuttle by 2005. Block One of the space station, which includes the manned laboratory modules and the polar platform, would be built and operated by 1997. Satellite servicing facilities and co-orbiting man-tended platforms (used for particularly sensitive experiments) would be added by the year 2000. The Tracking and Data Relay Satellite network (TDRS) would be in place with perhaps three satellites in operation by 2000.

Space science, applications, and exploration would focus in the early 1990s on missions delayed by the Challenger accident; among these missions are the Galileo probe to Jupiter, the Hubble Space Telescope, and the Gamma Ray Observatory. The last two observatory missions would be serviced by the shuttle orbiters throughout the decade and, sometime after 1995, would be joined by two additional orbiting observatories developed during the 1990s. New planetary missions, the Comet Rendezvous/Asteroid Flyby, and a Saturn probe would be in flight in the mid-1990s, as results from the missions to Jupiter, Venus, and Mars are analyzed. The Environmental Observation System, using the space station polar platform and other U.S. and allied spacecraft in higher orbits, would monitor natural and human effects on the Earth's atmosphere and climate by the late 1990s. The space station would also host an aggressive program of research on processing materials and on life sciences.

Research and Technology would be well-funded and oriented toward human voyages to the Moon or Mars, but actual missions to those destinations would still be in development.

NEW INITIATIVES

While proposals to go beyond the 1990s core program include some initiatives that do not involve manned exploration in the next two decades, human expansion beyond Earth's orbit is the major focus of these programs.

Infrastructure requirements of these new initiatives vary depending on the program adopted. The core space transportation system and the core space station are common to all the initiatives. Additional Earth-to-orbit transportation to carry people and cargo, and more facilities in orbit (beyond the shuttle system and space station) would be needed to support either the construction of space vehicles for a Mars expedition, or continuing logistical support for a lunar base. In-space transfer vehicles would be necessary to move large numbers of people back and forth to construction activities or a Moon base.

Space Science, Applications, and Exploration would be directed toward human expansion beyond the Earth's orbit shortly after the turn of the century. The new initiatives that emphasize a phased expansion, starting with a return to the Moon (as recommended by the National Commission on Space), feature a lunar base where astronomical observation would be undertaken and technologies developed to extract fuel and oxygen from lunar materials. A series of unmanned missions to Mars would probably be undertaken, leading to a manned mission as early as 2005 in those programs calling for such a mission. Unmanned missions to Mars would include robotic surveys and a sample return mission.

Research and Technology would be oriented to the problems of moving and sustaining humans in space. Manned initiatives planned for early in the next century would require a significant research effort, particularly in life science research aboard the space station to determine how humans best survive and function in space.

BUDGET-CONSTRAINED OPTIONS

Restricting NASA's annual budget to the 1988 level of $9 billion requires the core program to be *stretched out* well into the next century, or *restructured* to de-emphasize manned space activities.

Infrastructure development and operation dominates both the core program and more ambitious space programs. Stretching out the infrastructure investment plan means pushing back the space station into the next century and not expanding the capability for Earth-to-orbit or in-space transportation. Generally tight budgets would permit some operational savings, however, since restricted spending for space science would lower the demand for launch services. Restructuring NASA's program would involve changing the current program's emphasis on manned activities. The first step would be to cancel the space station, perhaps in favor of less capable but also less costly periodically manned space platforms. In such a program, the manned orbiter fleet would be used only where essential: to visit platforms and serve as an orbiting laboratory.

Space Science, Applications, and Exploration under either option would benefit from the eventual launch of the backlog of payloads and experiments delayed by the Challenger accident. Stretching out the core program would involve a slowdown in the development of a new space science mission, since funding for the space station would consume a large part of a reduced annual budget. Major observatory or planetary missions, or both, would be deferred until the late 1990s, and the Earth Observation System would be scaled down because the space station polar platform would not be available until after 2000. Restructuring would permit a quicker pace in scientific research, since more funds would be available and activities involving human flight scaled back. Neither option would enable human expansion beyond Earth's orbit in the foreseeable future; the stretched-out program would limit the pace of such expansion through budget constraints, and the restructured program would eliminate all such missions by conscious choice.

Research and Technology under a stretched-out option would be funded at the current level, but still directed toward a set of complex manned missions in the future. Under a restructured option, the research and technology program would be constrained in its funding but would be more focused on automated (as opposed to manned) space activity.

New Initiatives

Several major reports have evaluated the nation's space program and suggested that NASA should aim for new, even more ambitious goals in space and be given the resources to achieve them. The National Commission on Space (NCS) in its 1986 report, *Pioneering the Space Frontier* (the *NCS Report*), proposed a building-block approach, extending human activities from low Earth orbit to the Moon and Mars over the next 50 years. A 1987 report, *The Civil Space Program: An Investment in America* (the *AIAA Report*), by the American Institute of Aeronautics and Astronautics (AIAA), a professional society, advocated a similar agenda. A NASA report prepared by Sally Ride, *America's Future in Space* (the *Ride Report*), develops a set of options for a more aggressive space program that includes a manned sprint to Mars (a mission skipping a return to the Moon and proceeding to Mars as early as 2005), a lunar base, a more aggressive unmanned program of solar system exploration, and a sophisticated and extensive Earth Observation System. The *Ride Report*'s options are all structured to produce major results by 2010.

Manned initiatives leading to the Moon or Mars during the first decade of the next century would require spending above the core program level, and above NASA's Apollo peak spending of $22 billion in 1965. The cost estimate for the program contained in the *NCS Report* diverges sharply from that for the core program in the mid-1990s, increasing NASA's annual budget to $15 billion in 1995 and almost $25 billion by 2000. The funding requirements for the program outlined in the *AIAA Report* exceed those of the core program from 1989 onward, also requiring over $20 billion by 2000. The estimated cost of the *Ride Report* initiatives is even higher, requiring over $30 billion annually by 2000.

Budget-Constrained Options

Were the Congress to hold NASA's budget to its 1988 levels, NASA's program would either have to be stretched out or restructured. Stretching out the core program would involve delaying the space station program into the next century, and deferring additional investment in transportation. Restructuring the program would decrease the role of manned space flight and cancel the space station program in favor of using periodically manned facilities for materials research and unmanned scientific spacecraft.

The stretched-out and restructured programs differ most dramatically on the issue of the space station. Stretching out the current core program within a no-growth budget involves funding the space station at $1.5 billion annually and permitting NASA to carry budget authority forward to meet funding peaks as required. Other NASA activities would be slowed down to accommodate this funding, but less spending on transportation would be necessary in the 1990s as budget constraints slowed down the development of major payloads. The restructured program includes only $0.5 billion annually for activities similar to the space station--primarily for periodically manned orbiting laboratories and shuttle-based experiments. Funding in research and technology and in the space science and applications programs is below the core program levels, but above the stretched-out program estimates, since a part of the annual savings from the elimination of the space station program is redistributed toward these areas. Space transportation funding is increased to procure conventional rocket services that can meet the higher launch demand resulting from increased spending for space science and applications payloads requiring launch services.

WHAT IS AT STAKE?

Traditionally, the civilian space program has been justified as a means to realize human destiny, an investment in the international standing of the United States, and a provider of economic benefits. The first rationale is beyond the scope of this analysis, but the broad alternative paths suggested for NASA can be evaluated against their potential to maintain the U.S. position as an international leader in space and, in relative terms, against the extent to which they provide economic benefits. Yet, the uncertainties of estimating the technical and scientific returns to the NASA program prohibit comparing the civilian space program with other federal investment in science and technology or other federal spending that benefits society.

International Leadership

The consensus of recent studies of the civilian space program is that the core program would grant the United States a significant leadership position in civilian space efforts, despite the fact that the cost of being an international leader in space has increased as the cost of large-scale space activity has risen, and as more competitors--European nations, Canada, China, and Japan--have initiated serious civilian space programs.

The new-initiative packages would all serve to enhance U.S. leadership in space. The manned activities in particular would provide highly visible symbols of national technical competence. The restructured program, while forgoing leadership in manned space areas, would permit both a focus and leadership in automated space activities. The stretched-out program would provide for a space station early next century, but at the cost of reduced accomplishment elsewhere in the program.

Economic Benefits

The civilian space program provides an economic return by creating public goods and services, stimulating private-sector research and development, and directly encouraging the creation of new industries that use the space environment. In general, the more that is spent on space activities, the more benefits will be provided in these areas.

NASA's activities provide the public good of scientific and technical knowledge. Spending more on space science will provide more of this public good, but it is nonetheless difficult to judge if the benefits derived from, for example, a manned Mars mission, are commensurate with their cost. The NASA program also benefits the larger economy by stimulating private-sector research and development. NASA programs may create technologies that can be spun off to private firms and ultimately contribute to economic growth. Some analysts have suggested, however, that spin-offs are less likely to occur in the development of large operational systems, like the shuttle or the space station, than in the basic research and technology program. NASA may also indirectly improve private-sector research by enlarging the pool of scientists and engineers.

The attempt to encourage space-based industries is not new to NASA: satellite communications and land remote sensing (a form of sophisticated satellite photography) are already major examples. This type of industrial policy strategy now exists in the area of processing space materials, where prospects exist for improving earth-based products, and for manufacturing drugs and materials for advanced computer chips. The core program, through the space station, supports this type of activity, whereas new initiatives tend to emphasize providing public goods that would add to new space industries primarily in the infrastructure area. The stretched-out and restructured programs approach the processing of materials in different ways. The stretched-out option keeps the possibility of a permanently manned facility alive, but the implicit dilution of effort would leave the NASA program in the 1990s unable to devote significant resources to developing experiments with space materials and processing. The restructured option may allow these efforts to advance by targeting them for resources saved by eliminating other NASA projects.

In general, more ambitious programs will deliver more economic benefits. But it is difficult to determine whether these benefits are commensurate with the increase in costs, in relation not only to the set of space program options open to the United States, but also to broader scientific and technology options and to other federal spending.

INCREASING THE EFFECTIVENESS OF NASA's SPENDING

Regardless of whether the Congress calls on NASA to do more or less than the current program, pressure will be present to increase the effectiveness of NASA's spending. Several proposals in this area have been endorsed by NASA and are included in the current program. International cooperation in science and infrastructure is included--for example, European countries, Japan, and Canada would participate in the space station. The program also includes cooperation with other U.S. government agencies--for example, the Department of Defense in the space transportation area.

The Administration's 1989 budget request for NASA includes multiyear funding for the space station. This funding would put into effect a long-standing suggestion to improve the effectiveness of NASA spending by allowing the agency to plan and execute its programs without concern that subsequent Congressional action will force wasteful changes in plans. Were multiyear funding applied to many large NASA programs, an additional benefit would be to increase visibility for the many apparently small new programs that will require much greater support in later years. Multiyear appropriations would also increase the attractiveness of the United States as a partner in international joint ventures. The flexibility of the Congress in enacting deficit control measures, however, would be decreased. Moreover, those programs granted advanced appropriations could receive preferential treatment, perhaps unintended by the Congress, relative to other NASA activities or to unrelated spending should the Congress seek to reduce all spending by across-the-board freezes or cuts.

As NASA continues to devote a substantial part of its budget to developing and operating infrastructure, some have suggested that the federal government should encourage direct private investment in space infrastructure. NASA's 1988 appropriation called for the agency to conclude an agreement to lease the Industrial Space Facility, a proposed orbiting laboratory to be visited by the shuttle astronauts for the purposes of experimenting with life-support systems and processing materials in low-gravity conditions. The national space policy has directed NASA to purchase launch services rather than launch vehicles, to encourage private providers of such services. The key issues are a government commitment not to compete with the private sector, and guaranteed federal procure-ment of a substantial part of the private providers' initial offering of services to the market.

Advocates of this strategy argue that the private sector will be able to provide facilities and services more cheaply than NASA, thereby permitting the public sector to accomplish its business at a lower cost and perhaps inducing other private investors requiring space infrastructure to manufacture in space goods and services that are sold on Earth. The advocates' first point is untested, but is more likely to hold if the technology underlying the infrastructure is well understood. Their second point is also as yet unproven; in such areas as materials science, a long period of government support may be required to develop useful technologies and products, regardless of whether or not the costs of infrastructure and other services are reduced below current levels.

CHAPTER I

INTRODUCTION

During 1987, the National Aeronautics and Space Administration (NASA) focused its attention on returning the shuttle system to flight; it also took part in the Administration's reassessment of what direction the civilian space program should take for the remainder of the century. The conclusion of this reassessment, as expressed in the Administration's national space policy statement and NASA's fiscal year 1989 budget proposal, is that future program strategy will maintain its current emphasis on operating manned facilities in low orbit around the Earth (referred to as low Earth orbit), but that NASA should also adopt the goal of expanding human activity beyond the Earth's orbit.1/

Thus, the shuttle system would continue to be the hub of the civilian space transportation system, and substantial resources would be devoted to enhance its capability. More important, for the 1990s, NASA would continue to give its highest priority to a permanently manned space station. The President's budget submission to the Congress for fiscal year 1989 includes $6 billion (in current dollars) in funding for such a facility--$1 billion in 1989, $2 billion in 1990, and $3 billion in 1991.2/ Beyond these efforts, NASA's budget request for fiscal year 1989 includes funding for the Pathfinder Program, a research and technology initiative that will begin NASA's effort to expand human activity beyond Earth's orbit.

Hence, the Congress faces some difficult questions about the adequacy and affordability of the current civilian space program: whether or not major new initiatives are required to meet the nation's space policy goals, and whether or not such new initiatives--or even the current program--can be supported without significant funding in-

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1. Congressional Research Service, *Civilian Space Policy under the Reagan Administration: Potential Impact of the January 1988 Directive*, Report No. 88-237 (March 1988), pp. 8 and 9.

2. *The Budget of the United States Government, Fiscal Year 1989*, p. 2b-6.

creases. This Congressional Budget Office (CBO) study addresses the content, likely achievements, and estimated cost of a logical extension of the current program (referred to as the core program) and explores two alternatives to it that might be pursued through the end of the century. The study also considers methods to increase the effectiveness of NASA spending.

The study's analysis relies primarily on NASA planning documents and cost estimates, and on those of NASA's network of specialized Advisory Council committees. The broad outlines of NASA's core program include estimated costs and schedules for major investment projects, missions, and ongoing operations. The first major alternative to the core program is a set of new initiatives that proponents view as necessary to place the United States among the leading spacefaring nations at the turn of the century. A second alternative would be one of two scaled-down versions of the core program that could be supported without real increases in the NASA budget.

The core program and the two alternatives to it are largely based on the traditional rationales for the civilian space program. The United States has pursued civilian space activities for a variety of reasons. Manned space flight has been justified as an imperative of human existence. Its proponents view it as a manifest destiny, demanding a human presence as far into space as technology permits. The accomplishments of the civilian space program also contribute to the international presence and stature of the United States. More concretely, the civilian space program provides the public goods of scientific knowledge, spins off technology to unrelated areas that private firms can profitably exploit, and may demonstrate the economic potential of certain products and services that require the use of the space environment.

NASA's RECENT PROGRAM AND BUDGET HISTORY

A previous CBO study noted that the accident of the space shuttle Challenger in January 1986 would affect all NASA programs far into the future by requiring new expenditures for space transportation, delaying programs that depend on space flight (such as scientific payloads), and raising the implicit price of all activities that depend on space flight, including the space station.3/ Thus, during the 1990s, the U.S. space program will accomplish less than originally foreseen at a higher-than-expected cost. Nevertheless, the scientific benefits of the nation's investment in space infrastructure will be realized, albeit later than expected, when such projects as the Hubble Space Telescope, the Galileo probe to Jupiter, the Magellan probe to Venus, the Mars Observer probe, spacelab flights, and the Upper Atmospheric Research Satellite are launched over the next several years. The Challenger accident, while a significant influence on the NASA program, is not likely to change that program's essential elements as they have evolved since the successful conclusion in the early 1970s of the Apollo missions to the Moon.

Figure 1 shows NASA's budget and its major components over the past 19 years. The agency's real purchasing power declined from 1970 to a low point in 1975, stayed flat through 1978, and has increased slowly but erratically since that time. NASA's share of the federal budget reached almost 4 percent during the peak Apollo years of 1964 and 1965, but fell as low as 0.7 percent in the mid-1980s. Funding to develop, build, and operate the shuttle system--the first building block of the low-Earth-orbit infrastructure--increased through 1977 and remains a large share of the budget through 1988. Box 1 describes the shuttle or space transportation system and its various components.

The program to restore the shuttle fleet to flight and to replace the orbiter Challenger is responsible for the recent upward trend in the NASA budget. The investment in space transportation infrastructure dominates other components of the agency's program, since virtually all of the other program elements depend on the shuttle for access to space and, in many cases, for a base of operation once in orbit. The setbacks to the shuttle program have been more extensive than the loss of an orbiter. In fact, in reassessing the space transportation system, NASA has concluded that additional and unanticipated investment in space transportation will be necessary during the 1990s to complete the transportation portion of its program, and that the

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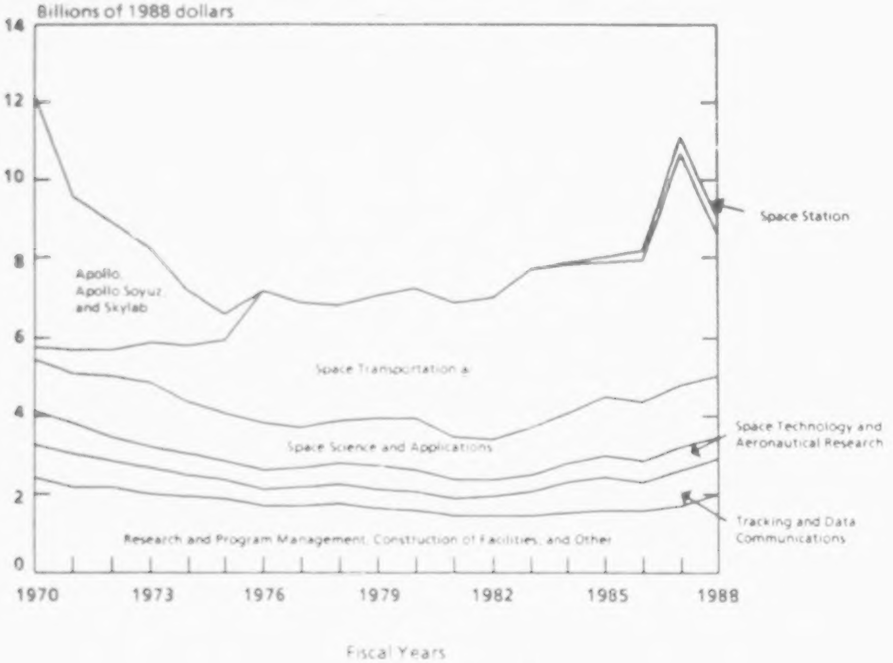
3. Congressional Budget Office, "The 1988 Budget and the Future of the NASA Program," Staff Working Paper (March 1987).

Figure 1.
NASA Budget, 1970-1988



SOURCE: Congressional Budget Office based on NASA budget plans as presented in *NASA Budget Estimates*, various years.

a. Includes expendable launch vehicles for space science and applications missions.

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manned shuttle should be complemented by a substantial number of expendable launch vehicles. The remaining major elements of the NASA program are space science and applications (including the missions to other planets, the astronomical observation platforms, and Earth observation), space technology and aeronautical research, and institutional support.4/

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4. This analysis does not discuss NASA's aeronautical research and technology program, although these activities are included at their current real dollar levels in all budget estimates.

BOX 1
THE SHUTTLE SYSTEM

The linchpin of the current NASA program is the space transportation system (sometimes called the shuttle system). Space science and technology programs currently depend on the shuttle system to launch satellites in orbit around the Earth, or probes to the planets, or to carry instruments and round-trip experiments. As a purely logistical matter, the over two and one-half year grounding of the shuttle system has left NASA with very limited access to space until the shuttle returns to flight.

Three airplane-like manned spacecraft, referred to as orbiters or shuttles, are the most visible part of the system. A fourth orbiter to replace the Challenger is being produced. During a shuttle flight, an orbiter is launched into space by two solid-fuel rockets (called solid rocket boosters), to which the orbiter is attached, and by three liquid-fuel engines that are contained in the spacecraft fuselage, but draw fuel from a large fuel tank (called the external tank) attached to the underbelly of the orbiter between the two solid-fuel rockets.

Each orbiter can carry a variety of cargoes to and from space--satellites, instruments, or a laboratory unit called a spacelab that expands the volume of space in which people can work. Shuttle-borne satellites that require orbits higher than 160 to 200 nautical miles are typically attached to rockets and carried in the shuttle cargo bay. After the shuttle reaches its orbit, the satellites are then launched by their rockets to their final Earth orbits or beyond to the planets. These "upperstage" rockets come in a variety of sizes designed to service different payloads.

The shuttle system includes a great deal more than the visible hardware and activity of a typical flight. Incorporated in the system are launch and landing facilities, manufacturing plants for major components (such as the booster rockets and fuel tanks), and a large institutional and management structure. These operations are spread over the major NASA centers, most prominently the Kennedy Space Center in Florida, the Marshall Space Flight Center in Alabama, and the Johnson Manned Space Flight Center in Texas. Personnel from both NASA and private contractors are involved.

Developing a Low-Earth-Orbit Infrastructure

The statutory basis of the NASA program is the Space Act of 1958, as amended (Public Law 85-568). The act is specific in including as objectives of the agency both the use of space for science and commerce, and the capability to reach space and function in it. This last objective--creating an infrastructure--has sparked the development and operation of launch and space propulsion systems, tracking and data support (both on the ground and via satellite), and facilities in orbit such as Skylab or the proposed space station.[5] The cost of such infrastructure investments is high and lasts for several years. The stream of benefits, however, can be substantial and accrue over a long period of time.

Currently, the NASA program is at the midpoint of an ambitious effort to develop an infrastructure that would enable manned and unmanned space activity to take place in low Earth orbit. Representing substantial past investments in this infrastructure, and accounting for over half of NASA's resources during the 1980s, are the space transportation system (the fleet of shuttle orbiters, facilities, and related equipment) and the Tracking and Data Relay Satellite system (TDRS, three satellites and a ground station, capable of replacing the global ground tracking and data communications network used by spacecraft in low Earth orbit).

NASA plans to continue its infrastructure investment program throughout the 1990s by developing and building a permanently manned laboratory facility--the space station--and associated unmanned platforms. Moreover, the space station is at the center of NASA's transformation from the single large project team, which landed men on the Moon, to an agency that develops, builds, and (in some cases) operates the infrastructure necessary to conduct science and commerce in low Earth orbit, as well as to provide a point of departure for exploration beyond Earth's orbit.

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[5] A series of Office of Technology Assessment reports provides a detailed account of the NASA program during the 1970s and 1980s and develops the concept of space infrastructure. See Office of Technology Assessment, *Civilian Space Policy and Applications* (June 1982); *International Cooperation and Competition in Civilian Space Activities* (July 1985); *Civilian Space Stations and the U.S. Future in Space* (November 1984).

Space Science and Infrastructure Investment

The space science and applications program includes a diverse list of activities. The planetary exploration and physics and astronomy programs together account for over 50 percent of the total space science and applications program, and illustrate a trend toward large-scale projects in these areas. Space applications include traditional satellite services--for example, telecommunications--and a newer set of activities such as processing materials in space. The space science and applications budget (excluding the expendable launch vehicle procurement included in the account in the early 1970s) dipped with the entire NASA program budget in the 1970s. Since 1985, however, it has consistently surpassed its 1970 real dollar level, even though the NASA budget as a whole has not.

In one sense, space science is the ultimate user and beneficiary of the infrastructure investment program. The infrastructure strategy should increase the productivity of space science projects by lowering the cost of delivering and operating science payloads. For example, a single shuttle flight could permit Earth, atmospheric, and astronomical observation to be undertaken and, at the same time, provide an orbiting laboratory for research on materials and life science. Moreover, the shuttle opens the prospect of servicing satellites in orbit, thus permitting sensors and instruments to be replaced without incurring the cost of building and launching a completely new spacecraft. The resources required to build the space transportation system, however, have necessarily limited the resources available for space science activities and, hence, the flow of new experimental results. In addition, expected decreases in the cost of launching the shuttle have not been achieved, since the space shuttle's current annual flight rate is far below that anticipated by its designer during the 1970s.6/

In part of the space science and applications program, the emphasis on large projects found in the whole NASA program is being replicated in miniature. For example, the physics and astronomy program focuses on developing, constructing, and operating the Great Observatory Program that would, if fully developed, consist of four

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6 Congressional Budget Office, *Setting Space Transportation Policy for the 1990s* (October 1986), p. 11.

orbiting platforms. The first two of these would be the Hubble Space Telescope and the Gamma Ray Observatory. The budget profiles of these projects are similar to other new space infrastructure investments--funding increases to a peak during the middle years of development and construction, and then tails off, with a long operating cost trail while the facility is used and scientific rewards are gained.

The Technology Base

NASA is often criticized for devoting too little of its budget to developing new technology and for undertaking too little basic research. The agency's real dollar spending in its space research and technology program has fallen in the post-Apollo era. The funds are specifically earmarked for basic research and technology activities untied to any particular development effort. These activities help to define the technical possibilities available for missions under long-term consideration--for example, a Moon base or a Mars colony--and may be helpful in determining the relative benefits, technical risks, and costs of alternative new missions.

Large development efforts such as the space shuttle or the space station programs undoubtedly help advance basic technology and, unlike generic technology efforts, are ends in themselves. However, even the best efforts to develop technology within a development program run the risk of failing to explore promising areas by being tied to a specific vision of a finished system. In a recent assessment of NASA's research program, the National Research Council concluded that the current emphasis on large operational programs like the shuttle has left too little funding for NASA's pure technology demonstration efforts and has seriously depleted NASA's stock of basic research and technology.7/

Institutional Support

NASA's institutional support budget includes research and program management (RPM), primarily federal employees and contract

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[7] National Research Council, *Space Technology to Meet Future Needs* (Washington, D.C.: National Academy Press, 1987), p. viii.

services, and construction of facilities. Taken together these expenditures have accounted for roughly 20 percent of the NASA budget. The agency's federal work force has dramatically declined since its peak Apollo year, 1967, in which almost 36,000 full-time and temporary personnel were employed. Federal personnel fell to 32,500 in 1970, to 25,500 in 1975, and to around 22,500 in the 1980s.[8] As the shuttle system moved toward operational status, the RPM budget began to increase--a trend that will continue if the infrastructure for low Earth orbit is operated as anticipated.

CHARACTERISTICS OF THE NASA PROGRAM

The focus of the post-Apollo NASA program on the development and operation of the low-Earth-orbit infrastructure, and the accompanying trend toward increasingly large space science projects, give the current program its structure. Taken together, the large scale of NASA's recent investments, the interdependence among infrastructure and project development and operation, and the long operational lives of projects and investments characterize major parts of the NASA program for the 1990s.

Large-Scale Projects

Throughout the development of the low-Earth-orbit infrastructure program, expenditures on the shuttle system have dominated the NASA budget. Within particular areas of the space science program, projects like the Hubble Space Telescope or the Galileo mission to Jupiter accounted for large portions of program budgets over many years. The NASA program epitomizes a general trend in U.S. science and technology policy toward large-scale projects, or "big science."[9]

This trend within the NASA program was recently noted by a NASA Advisory Council committee review of the space science and applications programs. It expressed concern about the balance within the program between big science and a lower-cost, more diversified set of projects.10/ The dominance of large projects in the NASA program is consistent with a governmentwide trend toward larger-scale projects--for example, the proposed Superconducting Super Collider (estimated to cost $5.3 billion in current dollars).11/ Since most significant scientific concerns may require enterprises on an ever larger scale, the trend itself may not be a matter of choice in the civilian space program. Nevertheless, the scale of space activity increases the cost of developing new endeavors, and makes the space program inflexible and vulnerable to cost and schedule delays in its major projects. The need for large-scale funding can stretch beyond development into years of operation--the fixed cost of operating a facility like the shuttle system is characteristically high. In both project development and subsequent operation, civilian space is becoming an all-or-nothing proposition.

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[8] National Aeronautics and Space Administration, *Pocket Statistics* (January 1988), p. C-24.

[9] Genevieve J. Knezo and Richard Rowber, "Big and Little Science," *Congressional Research Service Review*, vol. 9, no. 2 (February 1988), pp. 6-8, and Congressional Research Service, *World Inventory of 'Big Science' Research Instruments and Facilities*, Report No. 88-33SPR (December 1986).

Growing Interdependence

A second characteristic of the NASA program is a general interdependence among its elements. A planned layer of space platforms in low Earth orbit would be an indispensable element of specific space science missions. Programs looking "down" (Earth and environmental observation) and programs looking "up" (physics and astronomy) would have their instruments changed on platforms while in orbit, removing the need to launch new, single-purpose spacecraft. Like the shuttle, these platforms--the most important of them being the space station--would be designed to undertake many, rather than single, missions. The success of these efforts will be ultimately evaluated not only in terms of advances in the technology of space infrastructure and space science, but also in terms of the reduced cost of missions that are made feasible.

A review of the space science and applications program during the 1980s shows two distinct trends toward interdependence. First, the

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10. National Aeronautics and Space Administration, Advisory Council, *The Crisis in Space and Earth Science: A Report of the Space and Earth Science Advisory Committee* (November 1986), p. 12.

11. *The Budget of the United States Government, Fiscal Year 1989*, pp. 2b-6.

budget is dominated by a number of large projects that would depend on the shuttle system for launch or servicing in orbit or both, and on the space tracking and data communications networks (the TDRS and ground-based deep space network) to return data to Earth. Among these projects are the Hubble Space Telescope, the Gamma Ray Observatory, and the Galileo mission to Jupiter. Second, numerous smaller projects would be flown on a space shuttle round trip, including experiments in life sciences and processing materials, and a wide array of sensors designed to observe the Earth or outer space.

While increased interdependence offers the possibility of lower mission costs, it also increases the risks in cost and schedule faced by any particular mission. The planetary missions initiated in the mid-1970s, such as Galileo to Jupiter, depended on the then-untested shuttle system for transportation to low Earth orbit and on untested upper-stage rockets to launch the missions from low Earth orbit to their ultimate destinations. These missions have been vulnerable not only to their own technical problems or funding constraints, but also to those of the other projects (such as the shuttle) they have relied on. Consequently, planetary scientists have expressed a preference for traditional launch vehicles over the shuttle. The current program, however, includes many such missions, where cost and schedule risks are compounded by similar risks in the transportation and space station programs.

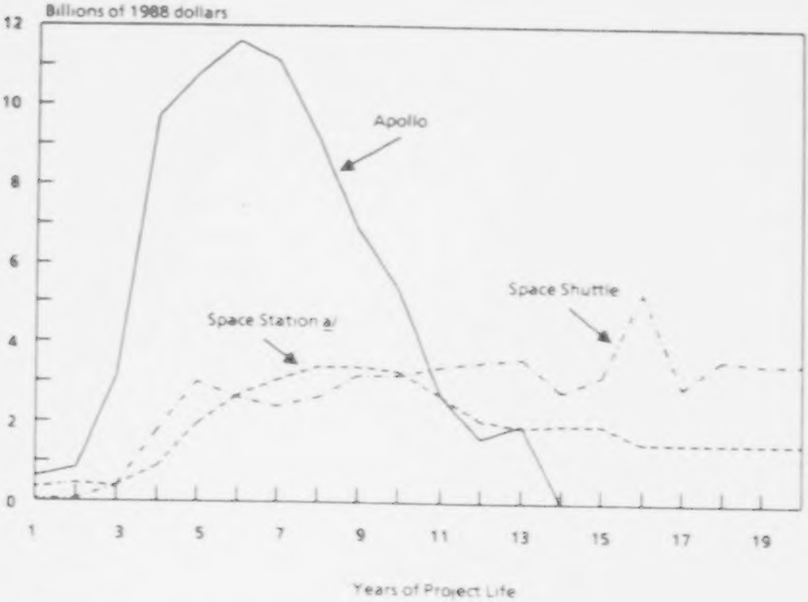
Long Life Cycles and Continuing Operating Costs

The shuttle program illustrates an important new budgetary pattern in the current NASA program: a number of years of high expenditures covering development and construction of a system, followed by an indefinite period of lower but continuous expenditures on operations and maintenance to allow the system to deliver its benefits. This profile differs from the Apollo profile, in which the absolute level of funding accorded a single program rose dramatically to dominate the agency's budget but then fell to zero over a span of 14 years. Figure 2 compares the absolute level of funding and its profile over time for the Apollo program with the two most prominent investments in space infrastructure--the shuttle system and the space station--the latter on a projected cost basis. From the vantage point of the whole NASA budget, the many years of operating costs associated with infrastructure investment imply an increasing NASA budget over time if a cycle is established of adding a new generation's development cost to the previous generation's operating cost.

Direction for the 1990s

The momentum of the NASA program over the last 15 years gives some indication of NASA's implicit plan for the 1990s. The implicit plan carries a basic set of costs and anticipated accomplishments that

Figure 2.
Cost of Space Programs



SOURCE Congressional Budget Office estimates and NASA budget estimates, various years

a Projected costs

constitute a core program, against which one can measure alternative programs incorporating major new initiatives. In this way, new initiatives can be examined in terms of how they would enhance the U.S. space program and how much additional growth in the NASA budget would be necessary to pay for them.

The long-term direction of the NASA program has become easier to predict because it includes projects with operation and maintenance costs extending long into the future, and because of interdependence among project elements. Today's program provides a basis for a new series of space efforts (as opposed to the Apollo program, which reached a logical conclusion after the series of manned moon landings in the late 1960s and early 1970s). The infrastructure built in this decade and the next will have a given set of applications, and these applications will form the core of the future program. Moreover, the decision to establish permanent human habitation in low Earth orbit implies continued investment in current or new manned transportation systems. Thus, the future NASA program will become increasingly determined by choices made years earlier: strong incentives will exist to fund new missions in order to rationalize the use of the infrastructure already provided, just as strong incentives now exist to buy the infrastructure needed to enable the new missions.

CHAPTER III

ALTERNATIVES TO THE CORE PROGRAM

The National Aeronautics and Space Administration's core program has been criticized on a number of fronts. At issue is how much of the nation's resources should be allocated to NASA, what the civilian space program should produce over the next two decades, and how important the space program is to the United States. The NASA budget for 1988 was $9 billion. The core program would require $16.4 billion annually by the year 2000. Aggressive new manned initiatives, such as a Moon base or a Mars mission, could increase the NASA budget to $30 billion annually by the year 2000. At the other extreme, some critics propose that NASA be restricted to its current spending level and design a program consistent with that funding.

POSSIBLE NEW SPACE INITIATIVES

Advocates of an expanded NASA program for the 1990s are in general agreement about long-term space policy goals, a sequence of steps to reach these goals, their supporting rationales, and, in very broad terms, how much an intensified civilian space effort might cost. Advocates of a larger space program draw support from a number of recent reports and studies, most notably *Pioneering the Space Frontier*, the report of the National Commission on Space (referred to as the *NCS Report*) and NASA's *Leadership and America's Future in Space* (referred to as the *Ride Report*).1/ These reports, and a growing number of others, advocate dramatic increases in NASA's activity beyond the core program. This study also focuses on a report by the American Institute of Aeronautics and Astronautics (the *AIAA*

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1. National Commission on Space, *Pioneering the Space Frontier* (New York: Bantam Books, 1986); National Aeronautics and Space Administration, *Leadership and America's Future in Space* (August 1987).

Report) as it examines the possible content of a NASA program including major new initiatives.[2]

The activities widely proposed for an intensified NASA program would include a broader application of space technology to Earth and environmental observation, new and more sophisticated unmanned exploration of the solar system, and manned exploration followed eventually by manned facilities on both the Moon and Mars. The sequence of steps necessary to carry out this agenda would require additional investment in technology and infrastructure in the early 1990s, and greater activity in the second half of the decade to begin specific missions. Ambitious manned initiatives, such as those proposed in the *Ride Report* and the *NCS Report*, could require the NASA budget to more than triple by the end of the century.

The initiatives included in this analysis by no means exhaust the options to expand the civil space program. Proposals other than those discussed below include establishing a geostationary manned space station, positioning large satellites to collect solar energy and beam power back to Earth, and constructing various types of facilities using the large external tank discarded by each shuttle mission.[3] The *AIAA Report* proposes less dramatic expansions of the core program for communications and land remote sensing satellites. However, the alternative policies presented here are those most widely discussed in the space community.

The new initiatives suggested in proposals to expand the NASA program illustrate the role of generic technology in new large-scale ventures, particularly those involving humans. Moreover, they reemphasize the central role of space infrastructure, since all of the initiatives require dependable and more capable transportation from Earth to low Earth orbit, in-space transfer vehicles, and more capacity to support humans once they are in orbit. Where manned operations are concerned, a faster pace in life sciences research is also a requirement. Advances in automated systems will also be necessary to undertake many of these initiatives.

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2. American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, 1987).

3. NASA Advisory Council, *Report of the Task Force on the Role of Man in Geosynchronous Orbit* (February 1987).

The general direction taken by the advocates of new space initiatives has been established for a long time. For example, in December 1969, the then NASA Administrator Thomas Paine outlined, in an article entitled "Next Steps in Space," a vision of NASA's future that included a reusable rocket plane to "shuttle" between Earth and Earth's orbit, deep space probes powered by nuclear rockets, and a permanently manned space station in low Earth orbit to support low gravity research, Earth and astronomical observation, and the servicing of applications satellites. Paine anticipated these developments would occur during the 1970s and 1980s, culminating with a manned mission to Mars in the mid-1980s.4/ Nuclear rockets and the timing hoped for by Paine and NASA have not come to pass, but the agency's program continues to emphasize the shuttle for transportation and the manned space station as a focal point of activity in low Earth orbit and as a starting point for future manned and unmanned activities in higher Earth orbits and beyond. Not surprisingly, the broad outlines of this strategy are similar to the vision articulated 17 years later by the National Commission on Space, chaired by Thomas Paine, in the *NCS Report*.

Rebuilding the Technology Base

A consensus among the advocates of new civilian space initiatives is that major new investments in space research and technology activities must be pursued to push beyond the space station era. The proposals for new initiatives tend to draw attention to the final results--for example, a Moon base. Yet, the most immediate activities necessary to realize these goals by the end of the century are in basic research and technology. The National Research Council presents the most detailed picture of the technology effort necessary to support a new generation of space missions.5/ Examining a 30-year period, the NRC's report analyzes the nation's technology needs in propulsion, support for humans in space, automation and robotics, power, materials and structures, and information systems and sensors, with a broad set of possible mission goals in mind. A central conclusion to be drawn

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4. Thomas O. Paine, "Next Steps in Space," *National Geographic*, vol. 136, no. 6 (December 1969), pp. 793-797.

5. National Research Council, *Space Technology to Meet Future Needs* (Washington, D.C.: National Academy Press, 1987), Chapter I.

from this analysis is that NASA's emphasis on large operational systems, such as those that characterize the low-Earth-orbit infrastructure project, has left the technology base too weak even to specify new mission goals without several years of substantial investment. The advocates of new initiatives may not accept the full implications of this conclusion that choices among mission options should not be made without narrowing the technical uncertainties surrounding the relative costs and schedules of different prospective missions. But most of them recognize that the first step toward the Moon, Mars, or a new level of Earth monitoring entails basic research and development of technology on Earth.

Expanded Earth and Environmental Observation

NASA has traditionally focused part of its research and development activity on applying space technology to service public needs or to demonstrate the potential of space activities for private profit. Examples are the early development of communication satellites, weather satellites, and the Landsat Earth remote sensing program. An expansion of space observation of the Earth and its environment is a logical next step along the road. The *Ride Report* describes an aggressive initiative of this type under the name "Mission to Planet Earth." Both the AIAA and NCS reports advocate similar, but slower, expansions of this type of activity.

The *Ride Report*'s "Mission to Planet Earth" scenario builds on the plan for an integrated Earth Observation System presented by the NASA Advisory Council.6/ The project would require new facilities in space and on the ground. Space assets would include:

- o Four platforms deployed between 1994 and 1997 in polar orbit to provide frequent coverage of the entire Earth;
- o A companion set of five platforms in geostationary orbit deployed between 1996 and 2000 to provide continuous coverage of particular parts of the Earth;

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6. NASA Advisory Council, Earth System Science Committee, *Earth System Science: A Program for Global Change* (1986).

- Sensors attached to the space station for atmospheric monitoring; and
- Enhancement and expansion of the Tracking and Data Relay Satellite system to manage the flow of information to ground receiving stations.

On the ground, receiving stations and hardware and software for data analysis would also be needed. In keeping with the direction of the entire NASA program, the platforms are intended to be serviceable either by unmanned automated vehicles launched from the shuttle or by an expendable launch vehicle. Once established, the system could provide traditional weather, land remote, ocean, and atmospheric sensing capabilities to evaluate natural changes in the ecology, as well as those caused by human processes. Practical applications of such a system include forecasting weather and climatic change, and monitoring levels of industrial pollution.

The *Ride Report* includes cooperation both internationally and among various government agencies in its "Mission to Planet Earth" scenario. It proposes that four of the nine platforms be provided by Japan and the eleven European nations belonging to the European Space Agency, and that the National Oceanic and Atmospheric Administration and National Science Foundations of the United States provide significant funding.

Unmanned Exploration of the Solar System

A second type of initiative emphasizing unmanned activity would be an aggressive expansion of U.S. unmanned exploration of the solar system. The NCS and the AIAA call for such a program, and the *Ride Report* features such activities as an independent option or as a precursor to manned exploration of Mars. The NASA Advisory Council has also presented a detailed inventory of planetary missions that could be undertaken during the 1990s.7/

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7. NASA Advisory Council, *Planetary Exploration Through 2000: An Augmented Program* (1986).

The core program for the early 1990s includes two proposed but unapproved missions--the Comet Rendezvous/Asteroid Flyby (CRAF) and a probe to Titan, the largest moon of Saturn, called the Cassini mission. (Both of these missions, however, are included as new initiatives rather than as part of NASA's core program in the *Ride Report*). A highlight of the next stage of planetary exploration would be an unmanned mission to return samples from Mars that would probably be preceded by several robotic rovers and would itself precede a manned mission. As the NASA Advisory Council notes, however, an intensified program of unmanned exploration has possibilities other than Mars open to it. Additional missions to the Outer Planets--Jupiter and beyond--could be pursued, such as a follow-on to the Cassini mission or missions to smaller bodies in the solar system--for example, a mission to return samples from a comet or an asteroid.

These more aggressive planetary missions would build on the results of the core program and use the transportation and space station infrastructure developed in the core program. Larger unmanned probes could be assembled in orbit. Missions would return their cargoes to the space station for preliminary analysis, and the samples would subsequently be returned to Earth by the shuttle. The technology necessary to mount this type of planetary exploration would include advanced robotics and automation.

Manned Exploration Initiatives

The most prominent proposed additions to the NASA agenda for the 1990s are manned missions to the Moon or Mars or both. The three overview studies all propose manned exploration and habitation of the solar system as ultimate goals for NASA. The *Ride Report* presents, but does not endorse, a "Humans to Mars" scenario that would launch a manned expedition on a 14-month round trip to Mars by 2005. This type of mission would require an aggressive life sciences program and extensive unmanned exploration of Mars during the 1990s. The *Ride Report* scenario proposes three missions to Mars culminating in a permanent outpost by 2010.

The NCS presents an alternative route to Mars that begins with a return to the Moon by 2005. Consistent with its building block approach to manned exploration of the solar system, the NCS proposes an orderly expansion of space transportation and operations infrastructure. For the 1990s, it focuses on Earth-to-orbit transportation, developing orbital transfer vehicles, and developing an Earth "spaceport" in an orbit higher than that of the core space station between the Earth and the Moon. Early in the next century, the *NCS Report* foresees a return to the Moon, from which a manned expedition to Mars would begin, perhaps as early as 2015. Mars would be approached via its moons, using a system of cycling spacecraft that would make the round trip journey to Mars and back every three years. This approach, when contrasted with that of the "Humans to Mars" in the *Ride Report*, leads to a 10- to 15-year delay in sending a manned mission to Mars, but permits developing an infrastructure (such as the "spaceport") that would facilitate sustained human presence beyond Earth. The AIAA assessment generally supports the Mars expedition of the NCS, but is not specific as to when further expansion of human space exploration would begin.

All three of the assessments of potential expansion of the NASA program ultimately advocate establishing a permanently inhabited outpost on the Moon. The outpost would require a logistical and transportation infrastructure capable of supporting sustained human presence. Exploration of the Moon and astronomy would be among the scientific activities undertaken at the outpost. Equally important, the Moon base would provide an opportunity to test whether space resources could support human habitation, since attempts would be made to extract oxygen and fuels from lunar materials and use these materials for a shield against radiation on the Moon and in space.[8]

BUDGET IMPLICATIONS OF NEW INITIATIVES

Adopting these new initiatives involving human presence beyond low Earth orbit would require an annual NASA budget in excess of $20 billion by the mid-1990s, and could require more than $30 billion annually by 2000. While the cost estimates provided for the core pro-

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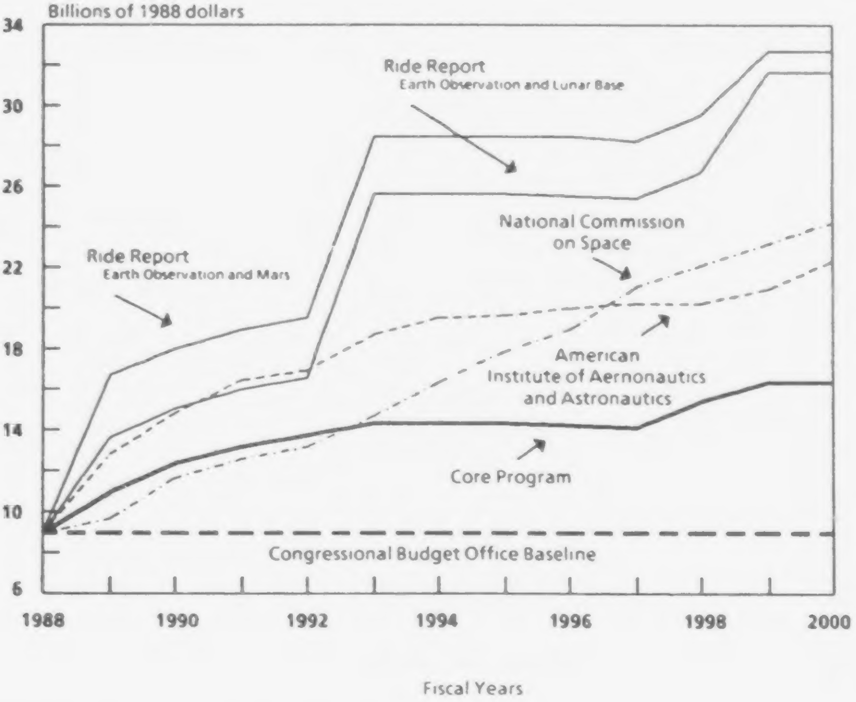
8. John S. Lewis and Ruth A. Lewis, *Space Resources Breaking the Bonds of Earth* (New York: Columbia University Press, 1987), Chapter 7.

gram in this analysis, and those for expansions of the NASA program in the three reports cited here, are at best rough beyond the three- to five-year time horizon, they indicate the levels of commitment required to pursue the types of goals included in each set of program activities. Figure 5 presents the Congressional Budget Office baseline (constant 1988 funding), the core program, and CBO cost estimates derived from the three summary reports.

The NCS and AIAA reports both provide the annual estimated costs for the programs they advocate, as shown in Figure 5. The *Ride*

Figure 5.
NASA Budget Options, 1988-2000



SOURCE: Congressional Budget Office estimates.

Report did not include dollar cost estimates of the initiatives it considered. Instead, comparative resource requirements were provided for each initiative in two bar graphs with undefined dollar scales. CBO estimated the annual budget requirements of the two *Ride Report* packages in Figure 5 in a two-step process. First, its established the value of the *Ride Report* scales by comparing the "Mission to Planet Earth" capabilities with the Environmental Observation System capabilities for which cost estimates were available, and by comparing the total requirements of the "Exploration of the Solar System"--the *Ride Report*'s unmanned exploration of the solar system scenario--with those of missions included in the proposal for which cost estimates were available.9/ Second, having established the value of the resource requirement scales, CBO broke down the total cost estimates for each project into annual costs that were consistent with achieving the schedule milestones for each *Ride Report* initiative. Each of the two *Ride Report* budget profiles includes the "Mission to Planet Earth" initiative and one of the major manned exploration missions, in order to provide comparability with the broader NCS and AIAA programs.10/

None of the programs presented represents a detailed plan including program and mission level schedules, cost estimates, and annual budgets. Thus, comparison among the total cost estimates is difficult. While the *NCS Report* provides both cost and schedule information, it does not provide a cost breakdown for even the largest subparts of its program. The *Ride Report*, even if costs are derived as described above, is similarly lacking in detail. The AIAA provides more detail in some areas, but does not include schedule milestones for the major activities it advocates, such as a Moon base and a manned Mars mission; instead, it refers in general terms to an "evolutionary path."

To the extent that the NCS program and the *Ride Report* options can be compared, the higher costs of the *Ride Report*'s Moon base option relative to the NCS's comparable milestone may be attributable to refinements in the planning for such a mission because the *Ride Re-*

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9. As given in NASA Advisory Council, *Planetary Exploration Through the Year 2000: An Augmented Program* and *Earth System Science: A Program for Global Change*.

10. An independent estimate of the cost of the *Ride Report* initiatives also placed the NASA annual budget above $30 billion by 2000. See Federation of American Scientists, *The Public Interest Report* (November 1987).

port's initial cost estimates were reviewed more than a year later than those of the NCS. In addition, more specialized reviews of requirements and cost have surfaced, such as the NRC's review of the research and technology program that advocates a $1 billion annual program to fulfill a set of mission requirements arguably less demanding than the *Ride Report* options.[11] Moreover, the NCS estimates probably do not take full account of the cost implications of the Challenger accident, a contention supported by the fact that the NCS program cost estimates are lower than the core program estimates until 1992. The high cost of the *Ride Report*'s "Humans to Mars," relative to all of the other programs, is driven by its timing, which requires a manned mission to Mars by 2005, as opposed to the more measured pace advocated by the *NCS Report* and the *AIAA Report*. This more measured pace is also suggested by the *Ride Report*'s Moonbase scenario, if the Moon base is viewed as a stepping stone to Mars.

BUDGET-CONSTRAINED OPTIONS

Even without new initiatives, NASA's plans to develop further and operate its low-Earth-orbit infrastructure during the 1990s will require increased funding. At the same time, concern over the growth of the federal deficit and the view that, independent of the deficit, current spending levels for the space program are adequate and should not be increased, suggest program options for NASA based on a fixed level of resources. Conceptually, two broad options are open: first, to slow down the core program by stretching out current projects and delaying the start of new projects, and second, to restructure the NASA program so that it will require less federal spending.

The two options developed below are constrained to constant dollar real funding. Any funding increases above this level will allow the option that stretches out the core program to progress with fewer delays and the option that restructures the core program to move more quickly. Modest rates of growth in the NASA budget however, would be unlikely to relieve the tension in the program between the costs of operating and investing in infrastructure and the costs of investing in space science and applications, and in new technology.

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[11] National Research Council, *Space Technology to Meet Future Needs*, p. 129.

Stretching Out the Core Program

Stretching out the core program would entail delaying the space station into the next century, lowering the level of space transportation operational activity and funding, restricting investment in the transportation system to modify the shuttle orbiter fleet, and moving forward in space science only as quickly as current real dollar funding would permit. Figure 6 includes a breakdown of the annual NASA budget during the 1990s under these assumptions. The dilemma of devising a broad outline for stretching out the NASA program for the 1990s in the context of a no-growth budget is that the scale of new investment required for the space station and the cost of operating and maintaining the transportation system leave little funding to exploit these assets for science, exploration, or commerce. These activities, however, are at least as central a purpose of the civilian space program as the development and demonstration of technology associated with developing and operating the station or the shuttle.

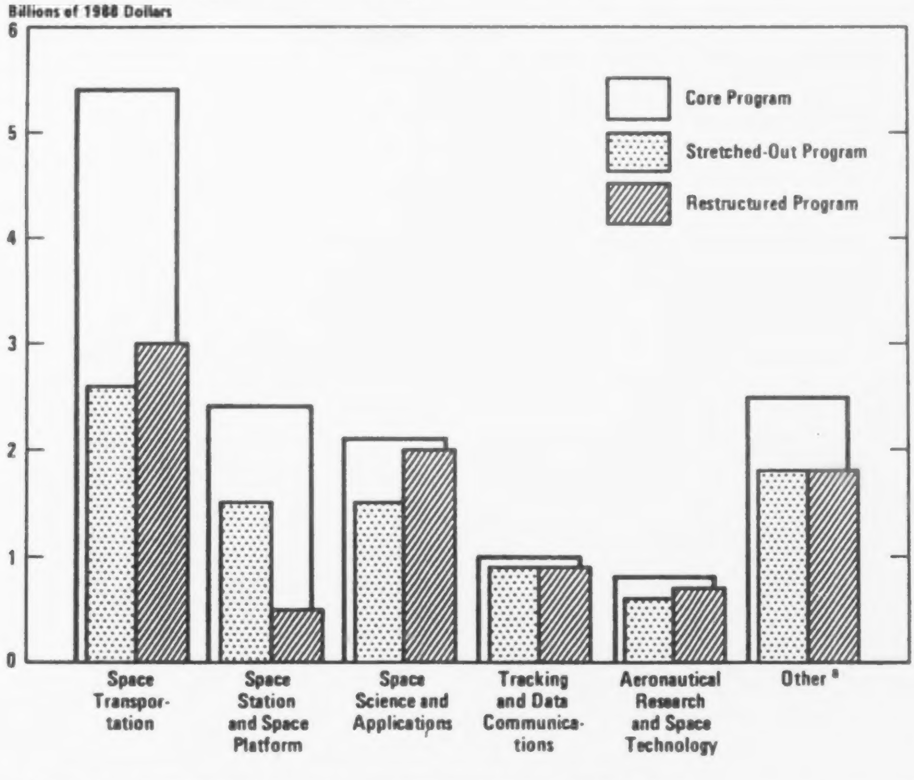
Stretching out the core program would leave the United States behind the Soviet Union in manned space flight. But a permanently manned space station could, nonetheless, be achieved by 2005. However, manned exploration of the solar system, such as a return to the Moon or a Mars mission, could not be pursued. The United States would still be among the leading space-faring nations in unmanned space applications and explorations, but would have made no significant advances in space processing or other commercial activities that require a human presence, unless the private sector pursues these activities at a level now unforeseen and without federal subsidy.

The level of risk accompanying this strategy is high since the transportation system would be placed under stress by the station project and other demands, and the paucity of funding for a replacement system would leave the program unprepared if the shuttle system needed to be replaced early in the next century. The problem of the program bucking against funding constraints would be continually present as overruns in the station program, or additional problems with the shuttle, would require either cuts in other activities or delays beyond 2005 to complete the space station.

Infrastructure Under a Stretched-Out Program. The estimate for the average annual expenditure on infrastructure development and operation for 1989 through 2000 is $8.8 billion for the core program. The current NASA budget is only $9.0 billion; therefore, any budget-constrained option requires major cutbacks in this area. In a stretched-out program, space transportation would be cut back. The space station would be restricted to an annual expenditure of $1.5 billion--a $1

Figure 6.

The Core Program and Budget-Constrained Options Compared (Annual Averages 1989-2000)



SOURCE: Congressional Budget Office estimates based on NASA data.

[a] Research and Program Management, Construction of Facilities, Technology Utilization, Commercial Programs, Safety and Quality Assurance.

billion reduction from its average annual requirements from 1989 through 2000 in the core program, and almost $2 billion below the core program's annual estimate for the space station for the peak years from 1993 through 1995.

Space transportation operating requirements during the 1990s average $3.3 billion annually if the core program levels include only shuttle operations, expendable launch vehicle operations, upperstage rocket procurement, and limited shuttle modifications. A stretched-out program would have lower operational requirements than the core program, allowing operational savings. If the stretched-out program required only half of the flight activity of the core program, savings of perhaps $750 million annually could be realized. This level of reduction assumes that the cost of an additional shuttle flight is $100 million and that five flights could be saved annually.[12] Additional savings of $250 million could be obtained by a 50 percent cut in expendable launch vehicles. Space transportation investment would be restricted to the marginal shuttle improvements traditionally included in the shuttle production and capability account. Prominent proposed infrastructure additions found in the core program (such as the Advanced Solid Rocket Motor, Shuttle C, and the orbital transfer and maneuvering vehicles) would be eliminated. A significant implication of the stretched-out budget is its effect on existing and improved manned transportation in the second half of the 1990s. No provision is made to maintain orbiter production as the core program does, nor is any significant investment in a replacement for the shuttle permitted.

The core program's spending for the space station rises to a peak during the 1990s and then declines. One approach to stretching out the current program is to view the space station funding as a residual after providing for other NASA activities. This approach would smooth out the spending pattern by pacing the program to fit within a constant level of annual new spending authority. If the program re-

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12. This assumption is reasonable if the Space Transportation System were "downscaled" well in advance of the canceled flights. NASA recently estimated the cost of each additional shuttle flight to be $45 million. This cost is estimated for an additional flight in a system expected to fly 8 to 14 times a year. Stretching-out the program downscales this system during the 1990s to five to seven flights annually and anticipates an additional $50 million saving per canceled flight. The savings of $100 million per flight are consistent with NASA's average variable cost estimate for a shuttle flight ($84 million, in 1982 dollars) before the Challenger accident.

quired increases in spending in a given year, then this approach would require the Congress to carry forward a significant amount of budget authority to accommodate future increased outlay requirements. If the stretched-out program restricts transportation to $2.6 billion per year and allows space science and applications, space research and technology, tracking and data communications, and all other parts of NASA's program to be maintained at their 1988 levels, then the residual funding for the space station is $1.5 billion annually.

Space Science and Applications, and Space Research and Technology. Both space science and applications and space research and technology would be decreased in a stretched-out program relative to the core program. Major projects in the core program--such as the two additional orbiting observatories, the Environmental Observation System, and the next round of planetary missions--would be slowed down or indefinitely deferred. Funds targeted for projects using the space station in the mid-1990s could be reprogrammed, however, and used for these other ends. Space research and technology would generally slow down, relative to the core program, by deferring major manned initiatives into the indefinite future.

Restructuring the Core Program

The essential theme of a restructured core program would be the deemphasis of manned activities. Savings relative to the core program would be realized in space transportation, and the space station program would be terminated. Increases in funding for a man-tended space platform and spacelab flights would partially offset these savings, however. To meet the budget constraints imposed by the current NASA baseline, space science and applications and research and technology funds would be restricted relative to the core program. But spending on space science and applications would still benefit, relative to the stretched-out program, because it would receive part of the savings that result from canceling the space station. Activities in both areas--research and technology and space science--would be steered away from the manned program toward an expansion of unmanned activities.

Restructuring the NASA program by de-emphasizing manned activities would represent a fundamental change in the U.S. civilian space strategy. Expanding human activity to the Moon and eventually to Mars would no longer be the implicit goals of the program. Manned activities would be confined to the shuttle and tending orbital platforms, if such facilities were judged to be useful. The United States would not contest the Soviet lead in long-duration space flight. But the program could maintain, and perhaps expand, the U.S. lead in automated space science and applications. The risk implied by such a program is less that it would not perform within its cost and schedule parameters, as that the overall results would be inadequate to meet national space goals.

Restructuring the Infrastructure Program. The core program devotes significant resources to developing, supporting, and maintaining a permanently manned space station during the 1990s. If this goal is forgone, an annual $1.5 billion that was to be devoted to the space station program in the stretched-out program would be freed for alternative uses. The restructured program allocates one-third of these savings to activities and facilities that would partially fill the gap left by the space station program, particularly in the materials processing area. Another $0.4 billion of the space station savings would be directed toward space transportation to cover expendable launch vehicle use, near the annual levels included in the core program, and developing an orbital maneuvering vehicle with automated servicing capability, capable of working with or without the shuttle. The additional funding granted to space transportation relative to the option of stretching out the core program would be to support the higher launch demand arising from platform servicing and space science, both of which would require more launch capability since they would receive more resources to develop missions than in the stretched-out program.

Available shuttle capability, a minimum of five flights annually, would be devoted to laboratory activities requiring man. All of the major cuts in transportation development included in the stretched-out program would be adopted in a restructured program, with the exception of funding development for automated in-space vehicles.

Infrastructure investment in on-orbit facilities would be more focused, but less ambitious, than under options that included the space station. Investments could be made in adding to the capacity of the shuttle mid-deck (the area where astronauts perform experiments on an average shuttle flight), in flying additional spacelab flights, or in buying or leasing a pressurized man-tended freeflyer, such as the proposed Commercial Developed Space Facility. Using space platforms, and extending shuttle flights and expanding their capacity to function as an orbiting laboratory, would implicitly lower the program goals in the manned spaceflight area. Such a program could provide a substantial capability to perform research on processing materials, but with neither the capacity nor the power envisioned for the space station. These substitutes for the space station would not allow learning about human space flight of long duration, nor would they represent a transportation way station for future manned missions to the Moon or Mars. But these goals would not be relevant to this option.

Space Science and Applications and Space Research and Technology. The space science and applications program would receive additional funding under a restructured program relative to the stretched-out program, since the budget pressure of a large, continuing investment like that for the space station would be decreased. The physics and astronomy, and planetary exploration programs would be relatively unaffected by the loss of the space station. The environmental observation program would require rethinking, in that the polar platform is conceived as the first spacecraft carrying the instruments for the environmental observation system. The growth of the life sciences component of space science and applications included in the core program would be unnecessary and could be reduced, since ambitious manned missions are not envisaged for this option. Growth in the processing of materials area would still be necessary to support the activities undertaken on the shuttle and man-tended platforms.

Space research and technology could receive additional funding under a restructured program, and, like the space science and applications program, could redirect its efforts toward unmanned rather than manned missions.

CHAPTER IV

EVALUATING CIVILIAN SPACE POLICY OPTIONS

The options before the Congress in civilian space policy require widely different resource commitments over the next decade. This chapter evaluates these options in light of the rationales traditionally used to support space activity. The Congress faces a crucial choice regarding the future of the U.S. space program. If it seeks international leadership--particularly in manned exploration of the solar system--then it must allow for as much as a threefold increase in the National Aeronautics and Space Administration's spending over the next decade. If it seeks to maintain NASA's spending at the 1988 level, it must forgo preeminence in space and direct NASA to exercise more limited leadership in particular areas and, ultimately, redirect its activities away from manned to unmanned ventures.

Should the Congress choose to support the core program, the United States is likely to be a leading space-faring nation in the late 1990s. Along with this leadership, the U.S. economy at large could benefit from spin-offs of NASA technology and research and development programs. At a minimum, the stage would have been set for future new commercial endeavors, although the prospects for new successful commercial activities in space are unknown.

It is impossible to determine, however, whether the increased benefits of a more ambitious program would be commensurate with the increased cost and risk. The most aggressive new initiative, the *Ride Report*'s "Humans to Mars," would raise the NASA budget from its level of $9 billion in 1988 to $33 billion in 2000, 50 percent above the $22 billion spent in 1965, the peak Apollo year, and twice the core program's $16.4 billion estimate for 2000.

Alternatively, NASA's program could be redesigned to fit the baseline budget, which holds future funding at 1988 levels. Adopting either of the two constrained budget options described in Chapter III would require the United States to relinquish the possibility of leadership in manned space flight at least for the immediate future, along with the direct and indirect economic possibilities of such leadership. The first option, stretching out the core program, would leave open the possibility of accelerating the program if the Congress chose to provide increased resources in the future. But it would also be likely to spread NASA's resources thinly over too many different areas, deferring several projects and accomplishing few. A restructured core program that fits the baseline budget (constant 1988-level funding), by de-emphasizing manned activities in favor of automated pay-loads, is likely to be more productive in terms of international space leadership and as a contributor to the economy, because it concentrates resources in fewer areas. It does not, however, provide the infrastructure that would be necessary for ambitious manned missions, such as those to the Moon or to Mars, in case the Congress should change its mind about the direction of the space program.

A difficulty in choosing among these alternative programs is that cost, or at least its order of magnitude, is more easily measured and foreseen than benefits. The types of benefits that might accrue include those that have justified past space policy: satisfying the inclination toward expanding human presence beyond the Earth, maintaining international leadership, and achieving economic benefits (both general and those specific to certain industries). The first two types of benefits are intangible, and therefore unmeasurable. Regarding the third, enough is known to evaluate the options relative to one another, but not to compare the benefits of civilian space spending with the possible results of other science and technology options or the general benefits to society from other types of federal spending.

MANIFEST DESTINY AND INTERNATIONAL LEADERSHIP

Advocates of space exploration argue that it is the manifest destiny of the human race to explore and populate the solar system. They argue that the international prestige and national security of the United States are enhanced by space leadership that includes not only technical competence, but also, as stated in the *Ride Report*, "the active demonstration of those capabilities."[1]

The manifest destiny case is certainly beyond the scope of this analysis in that it is clearly an issue related to values. A recent editorial stated that "Mars will be developed because it is there, just as America was."[2] However, even if that argument is accepted, the timing of human expansion is an open question. The issue of space leadership and its benefit to the United States, independent of its economic benefit, can be more concretely addressed.

The genesis of NASA and the civil space program was the contest for leadership between the United States and the Soviet Union. The military rivalry between the two superpowers produced rockets capable of placing satellites in Earth orbit, as well as delivering nuclear weapons. As the United States and the Soviet Union vied for successive first achievements in manned space flight, eventually racing to land a man on the Moon, the competition in the civilian space arena assumed ever larger proportions as an indicator of the relative merit of two radically different social systems.[3] Currently, the competition between the United States and the Soviet Union in civilian space continues to have implications in the international arena, but less so than during the 1960s.

The question that must be asked of the leadership standard is how much "international prestige and standing" is obtained by asserting leadership in civilian space and, if leadership is a goal of public policy, what is the cost of international prestige purchased by an aggressive civilian space program? Leadership as a space-faring nation could provide the United States with more international prestige than a stronger national defense, universal catastrophic health care, a superconducting super collider, or a smaller public-sector deficit. Unfortunately, the reverse can be asserted with equal certainty, since leadership is a perceptual issue when stripped of its economic components.

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1. National Aeronautics and Space Administration, *Leadership and America's Future in Space* (August 1987), p. 12.

2. "Why Russia Does Better," *The Economist* (October 3, 1987), p. 15.

3. Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), and John S. Lewis and Ruth A. Lewis, *Space Resources Breaking the Bonds of Earth* (New York: Columbia University Press, 1987), Chapter 2.

Thus, the first two points in support of expanding the civilian space effort rest on value judgments.

While the ultimate value of leadership in civilian space cannot be measured, the degree to which the various options for the NASA program are likely to provide "space firsts," or the highest quality of space activities and facilities, can be evaluated. Not surprisingly, the more resources that are devoted to space, the more leadership is gained. But even assuming large increases in the NASA budget above the core program, the United States might still have to focus its efforts on specific areas rather than trying to achieve leadership across the board. At the other extreme is the question of which of the budget-constrained strategies--stretching out or restructuring the core program--would be likely to contribute more to leadership, albeit on a smaller scale.

As leadership is a comparative standard, a general point should be made concerning the relative capabilities of U.S. adversaries and allies alike. During the Apollo era, the United States and the Soviet Union were the only contestants in the "space race." Any advantage either nation enjoyed by virtue of its pioneering status has now diminished, since space technology has spread to other advanced nations that are willing to pursue research in basic science, technology, and commerce in space. The implication is that the "latecomers" will rapidly close the gap with the leaders, at a cost significantly lower than that borne by the leaders in establishing the initial position of strength.4/ The cost of the new initiatives illustrates this point: the cost of restoring a leadership position, arguably not as dramatic as the leadership created by the Apollo program, requires a NASA budget in excess of $30 billion by the year 2000, more than $8 billion higher than was necessary in 1965, when the height of the Apollo effort was reached. In short, U.S. space leadership will prove increasingly difficult--and costly--to reassert and maintain.

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4. Kenneth S. Pedersen, "Changes and Challenges," in Molly K. Macauley, ed., *Economics and Technology in U.S. Space Policy* (Washington, D.C.: Resources for the Future, 1987), pp. 173-199.

The Core Program

The consensus of a number of recent studies is that the core program will maintain the U.S. position as a leader among space-faring nations. The NASA Advisory Council assesses the leadership potential of the core program for the late 1990s as follows: "In absolute terms, the U.S. civilian space program will be larger (with the possible exception of the Soviet Union), more comprehensive, and more technologically advanced than any other." But, the report continues, the size of the U.S. lead will be less than in the past as foreign programs increase their effort.5/

The *Ride Report* measures the space leadership potential of national programs against a progressive continuum of "leadership stages" from "pioneering" through two intermediate operational stages to "commercial viability." By this standard, the core program is adequate to provide leadership in the late 1990s. The core program represents a leadership position, as defined by the *Ride Report*, by advancing the U.S. program in those areas related to the infrastructure investment program--high Earth orbit, low Earth orbit, and supporting technologies and transportation. Core program missions in planetary exploration, physics and astronomy, and environmental observation would also be consistent with leadership as defined by the *Ride Report*.6/ On the other hand, by the report's measure, the core program is lacking in that it does not provide a strong enough foundation to move forward in the future, particularly where manned exploration is concerned.

New Initiatives

The basis of the proposals to provide NASA with substantial new objectives and the resources to obtain them is the claim that the United States is losing its leadership position. Given that, it is not surprising that all of the new initiatives reassert the U.S. position as the preeminent space-faring nation. According to the *Ride Report*, adopting

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5. NASA Advisory Council, *International Space Policy for the 1990s and Beyond* (October 1987), p. 16.

6. National Aeronautic and Space Administration, *Leadership and America's Future in Space*, pp. 15-19.

either the lunar outpost or the Mars mission goals would reassert U.S. leadership in manned space activity. The "Mission to Planet Earth," alone or in combination with either of the manned exploration missions, would push forward the U.S. program in activities and supporting technologies in Earth's orbit. The reports of the National Commission on Space and the American Institute of Aeronautics and Astronautics propose similar activities and would therefore provide similar advances.7/

Budget-Constrained Options

Neither stretching out the core program nor restructuring it would place a high priority on leadership. Were the Congress to choose either, it would implicitly place a low value on leadership in space as a national benefit, and reject the proposition that the civil space program should be a higher national priority. Nevertheless, each of the baseline options has distinctly different leadership implications.

A stretched-out program is less likely to produce any tangible leadership results than a restructured program by virtue of its diffusion of resources over many different areas. In the current fiscal environment, the pressure to provide funds simultaneously to operate existing infrastructure, the shuttle system (inclusive of its spacelab and scientific instrument pallets), and the Hubble Space Telescope, and to build new infrastructure (the space station) is likely to result in underfunding those operations already under way. Pressure to build the large projects would result in lower priorities for small science and limited mission spacecraft, at a time when many analysts have suggested the program could enhance its productivity by reemphasizing this type of mission.8/

The restructured program would probably permit more progress and leadership in the areas where program resources were focused. For example, research and technology development could be reoriented toward a leadership strategy in unmanned, automated systems.

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7. National Commission on Space, *Pioneering the Space Frontier* (New York: Bantam Books, 1986), p. 30. See also American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, 1987), p. 25.

8. NASA Advisory Council, *The Crisis in Space and Earth Science* (1986), Chapter I.

Space science activities would be planned around unmanned technologies and ultimately benefit from the refocused research and technology program. The manned portion of the program, using the spacelab and perhaps a periodically manned, free-flying laboratory could be aggressively pursued and well funded, thereby providing a potential for leadership in processing materials in space. But leadership in manned operations in low Earth orbit or manned exploration of the solar system would be abandoned.

ECONOMIC BENEFITS

Advocates of the civilian space program point to several types of economic benefits associated with the NASA program. First, NASA provides the public good of increased scientific and technical knowledge and contributes to national security in areas such as space transportation. Second, in the process of undertaking research and development, NASA encourages private firms to increase their independent spending, thereby increasing the level of such spending economywide and contributing to economic growth. This process may work through spin-offs of products or techniques, or less directly by increasing the economy's supply of scientific and technical talent.

A final type of economic benefit of the NASA program noted by supporters is its potential to create new space industries. This more explicit industrial policy rationale has in the past focused on the satellite communications industry and land remote sensing (a form of sophisticated satellite photography). Current areas in which NASA is directly involved in encouraging commercial activities include processing materials in space and private-sector provision of space infrastructure.

Public Goods

General advances in science and technology are usually classified by economists as "public goods." An essential characteristic of a public good is that it contributes to social welfare but that this contribution cannot be fully captured by private investors in the form of profit. As a consequence, private firms lack the incentive to produce the good, and it remains underproduced unless the government intervenes. Such public goods certainly include the knowledge gained about the universe and its origins, or about the history of the Earth and the solar system through planetary exploration and environmental and solid Earth observation programs. The federal government provides the public good of scientific knowledge through a variety of activities, including the National Science Foundation and the National Institutes of Health. As there is usually not a private market standard against which to value the public good of scientific and technical knowledge, a comparison of the costs of each mission is often substituted as an alternative, however incomplete such a comparison may be.

Economic Growth and Civilian Space Expenditures

The argument that current federal space expenditures enhance the nation's technology base and that of specific U.S. industries is more easily defined and analyzed than the other points made in support of expanding the NASA program. Advocates of a more aggressive space program argue that it is vital to the technological standing of U.S. industry. For example, the American Institute of Aeronautics and Astronautics states that "throughout our short two hundred years the chief source of new wealth has been the new technology derived from research and development," and that "investments in the civil space program . . . bring a high return in future revenues and jobs." Moreover, in this view, "a vigorous civil space program is a key element in economic competitiveness."[9]

Economists agree with the larger point in the advocates' case, but they may have reservations about how expenditures for the NASA program fit into the picture.[10] While research and development may not have been the most important element of economic growth throughout the history of the United States--natural resources, investment, and education were as important--research and development has assumed a very prominent position in U.S. economic growth since the end of the Second World War.11/

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[9] American Institute of Aeronautics and Astronautics, *Civil Space Program: An Investment in America*, p. 1.

[10] Comptroller General of the United States, *NASA Report May Overstate the Economic Benefits of Research and Development Spending* (General Accounting Office, October 18, 1977).

Moreover, the federal government has played an important role in undertaking, funding, and indirectly stimulating private research and development.12/ Since 1953, the federal share of total research and development has risen from 54 percent to 65 percent in 1965 and fallen to 46 percent in 1984. Most of this change can be explained by the fall in civilian space spending in the aftermath of the Apollo program.13/ The effect of federal research and development spending on private spending in the same area is generally seen as mildly stimulative. Recent studies (conducted under a variety of different methodologies and different time periods) estimate that a $1 change in such federal spending produces a change in related private spending ranging from minus 8 cents to plus 56 cents.14/ While NASA's independent effect cannot be evaluated, NASA is the most significant federal research and development agent after the Department of Defense. The private marketplace undervalues science and technology, because individual firms cannot fully capture the benefits of research and development in their balance sheets. The federal government's encouragement of private-sector research and development, therefore, benefits society as a whole.

During the 1960s, the connection between economic competitiveness and civilian space spending was argued largely in terms of spin-offs. Products like the integrated circuit, used in the Apollo program, found broad application throughout the economy. This government spending on science and technology also increased the pool of scientists and engineers. In the short run, the supply of

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11. Angus Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, vol. XXV (June 1987), pp. 649-698.

12. Congressional Budget Office, *Using Federal R&D to Promote Commercial Innovation* (April 1988).

13. Nathan Rosenberg, "A Historical Overview of the Evolution of Federal Investment in Research and Development Since World War II," paper commissioned for a workshop, "The Federal Role In Research and Development" (November 21-23, 1985), p. 16.

14. Nestor E. Terlecki, "Measuring Economic Effects of Federal Research and Development Expenditures: Recent History with Special Emphasis on R&D Performed in Industry," paper commissioned for a workshop on "The Federal Role in Research and Development" (November 21-23, 1985), pp. 23-25.

scientists and engineers is relatively fixed. Increases in the demand for these workers, therefore, initially lead to increases in their salaries. Over a number of years, higher salaries draw more people of higher quality into these professions.

These indirect effects certainly occur and are positively correlated with the level of private research and development spending, and technical change. The NASA program has long recognized this potential and has sought to promote it actively through its technology utilization program. But the evolution of the larger NASA program during the 1970s toward infrastructure investment and away from basic technology development may have diminished the flow of spinoffs. NASA's concentration on infrastructure, therefore, may involve utilizing technology rather than creating it. Nevertheless, aggressive increases in space spending, particularly in the basic research and technology program, will undoubtedly result in technologies that can be applied in the private sector.

The economic rationale for more resources for the space program has increasingly emphasized a direct industrial policy role for NASA. As an agent of industrial policy, NASA, in conjunction with private firms, sets out to develop specific products, processes, or technologies with precise market objectives. The core program's space station initiative is frequently justified as an infrastructure investment that will allow U.S. firms to increase their market share in areas such as pharmaceuticals and materials used to manufacture electronic components. The Administration's space policy of 1988 added an emphasis on private-sector investment in infrastructure that would receive a variety of direct and indirect supports from the government. These supports include deferred launch payments, technical cooperation, and, most important, a government commitment to play the role of "anchor tenant," in essence creating a demand for the product financed and operated by private capital.15/

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15. Congressional Research Service, *Civilian Space Policy under the Reagan Administration: Potential Impact of the January 1988 Directive*, Report No. 88-237SPR (March 1988), pp. 18-21.

Economic Benefits and NASA Program Options

Were the broad options for the civilian space program to be evaluated solely against narrow economic concerns, much as a private investor evaluates investment opportunities, two points would stand out. First, the set of options open to the investor are far broader than those in the civilian space area; and second, the uncertainty of returns in scientific enterprises, particularly in civilian space, makes it difficult to distinguish among space policy options. The comparison of options that follows can provide only a broad characterization of the likely returns of the program options. The evaluations are based on intentions rather than the possibility of success.

The Core Program. The core program will increase the output of scientific public goods by the civilian space program, stimulate private research and development through spin-offs (most likely those associated with the space station), and open the possibility of new space-based businesses in the private sector.

The provision of public goods in the area of science and technology depends on substantial increases in the level of spending. The effectiveness of this spending is, as noted earlier, a major test for the strategy of infrastructure investment. Each major investment project--the space shuttle, the space station, the Great Observatories, the Environmental Observation System, and the new generation of planetary probes--must produce a greater scientific return than the previous generation of space science in order to justify the high levels of investment necessary to bring the current generation into operation.

The core program's indirect effect on the larger economy is likely to be closely associated with the space station. Spin-offs are inherently unpredictable, but the direction of new expenditures indicates where they might be created. The most technically challenging aspects of the space station include its self-contained environmental system and various applications of robotics and automation. Expenditures in space transportation would be large but tied to the shuttle system. In critical areas like data processing, therefore, the stream of technical benefits is likely to flow from the larger economy to NASA rather than from NASA to the economy.

The most uncertain economic benefit of the core program is its influence on new space-based industries. Procurement of services from the private sector for government use will occur in the areas of the expendable launch vehicles and infrastructure to support the processing of materials. In the case of the former, NASA demand will reinforce demand from the Department of Defense, establishing a foundation that will help U.S. producers to compete in the global launch services market.16/ A potential exists to create new space-based processing activities, but these possibilities are generally viewed by the scientific community as occurring in the next century, and then only after a period of basic research and technology development that includes the early years of space station operation.17/

NASA has historically maintained an interest in satellite applications with commercial potential. The core program, however, does not include significant support for these areas consistent with Administration policy. Thus, the core program can be expected to contribute little to the technology base and economic health of the communications satellite and land remote sensing industries.

New Initiatives. Since the new initiatives build on the core program, their economic value lies in the economic benefits they create beyond those attributable to the core activities. In the area of public goods, higher spending should deliver more results--for example, a more aggressive planetary exploration program--but probably at a diminished rate for each new dollar of spending. The value attached to manned exploration and presence in space is paramount in this case, since most of the new initiatives involve new manned space activity. An exception is the aggressive development of an environmental observation and monitoring system that holds the promise of substantial improvement in delivering the public goods of monitoring pollution and forecasting weather.

Among the initiatives that would require a major increase in funding, the most promising areas for economic benefits--a lunar base or a Mars mission during the 1990s--are also the least predictable.

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16. For discussion of the role of government demand in the global launch market, see Congressional Budget Office, *Setting Space Transportation Policy for the 1990s* (October 1986), Chapter IV.

17. National Research Council, *Industrial Applications of the Microgravity Environment* (May 1988), p. 3.

New initiatives of this type would require substantial increases in the basic research and technology budget above the core program levels. Advances in materials, power systems, electronics, robotics, and computation would be among the areas focused on in developing technology. But it is impossible to foresee in which, if any, of these areas a spin-off comparable to the integrated circuit might occur.

The creation of new space-based industries is not a focus of any of the new initiatives per se. The increase in the demand for launch and in-space services required to carry out any of the initiatives would create new commercial prospects. It could also even lower the cost of getting into and operating in space sufficiently to induce new independent commercial activity. More visionary new industrial possibilities involving the use of space resources for fuel and oxygen would certainly be opened by the manned initiatives.

Budget-Constrained Options. The budget-constrained options spend far less on space than the core program or any of the new initiative packages; accordingly, they would deliver fewer benefits. The variables differentiating the stretched-out from the restructured program in the leadership area also apply in considering economic benefits. The spreading of resources made necessary by stretching out the core program would increase the cost of each project, if only because fixed costs are borne over a greater number of years. Moreover, infrastructure investments would not be used productively because operating funds would be limited. The restructured program would not have these problems.

A smaller civilian space effort cannot be expected to deliver the benefits of a program three times its size. But the alternatives confronting the Congress are broader than a larger or smaller space program. In the science and technology area alone, large projects such as the superconducting super collider or increases in the budget of the National Science Foundation may be superior alternatives to spending more on space. Broadening the scope of choices beyond science to a variety of other options, many of which provide public goods and commercial spin-offs to the larger economy and encourage the creation of new commercial enterprises, further complicates matters. The uncertainties surrounding many of the benefits of the civilian space effort prevent comparing it definitively with the array of other spending options open to the Congress. Within the context of the space program alone, however, it is clear that the greatest contrast in budget requirements occurs in the comparison of ambitious manned space initiatives, which require substantial increases in funding if they are to be undertaken in the near future, with the more modest funding demands of unmanned, robotic space exploration and research programs. Choices among the options presented in this study depend to a large extent on the goals of U.S. space policy.

CHAPTER V

INCREASING THE EFFECTIVENESS OF NASA's SPENDING

The tension between the National Aeronautics and Space Administration program and its budget is likely to be present regardless of the levels of appropriations provided or the ambitiousness of the agency's goals. A number of proposals have been put forward to increase the effectiveness of NASA's spending. Some are under active consideration and represent positions supported by the agency, such as increased international cooperation in large-scale science missions, and cooperation with the Department of Defense in developing new space transportation systems. Others are related to the budget process and include advanced appropriations for large infrastructure projects like the space station. Finally, a set of proposals has surfaced calling for broader private-sector investment in space infrastructure, in some cases combined with a restructuring of NASA that would divest it of operational responsibility for the infrastructure it develops.

International Cooperation and Coordination

Cost sharing with an international partner can lower the cost to the United States of a given mission and its benefits. The magnitude of this saving depends on the nature of the cooperative venture and the partners involved. Assuming no changes in mission characteristics or international differences in the production cost of space hardware and services, and no significant duplication of expenses in administration or planning and coordination, the cost of a mission will not be increased by cooperation. As a practical matter, these circumstances may not be present and, as some have argued, international cooperation may actually increase mission costs. Nevertheless, if pure scientific results are the objective of the mission, a commodity unaffected by joint ownership, the United States will increase the return to its investment through cost sharing even if total cost per mission increases as a result of coordination problems, technology disparities, and the like.

The core program includes both large and small international cooperative ventures, from coordination of separate spacecraft observations in the solar physics program to the space station partnership involving the United States and 13 partners. The projected cost of a manned mission to Mars has led to proposals to join with the Soviet Union in such an enterprise. Proposals made to intensify and expand the observation of Earth also call for international cooperation.

Cooperative ventures might also affect the magnitude and distribution of benefits. In the case of pure science missions undertaken with Japan, Canada, or the European Space Agency--political allies of roughly equal technical competence--the benefits of such missions are largely unaffected by international cooperation. Sharing scientific results with partners does not diminish the value of these results to the United States. As the type of mission moves toward space applications with commercial potential, economic rivalry assumes a more prominent role. In this case, the results of a specific mission may be translated into an economic gain for a pioneer that cannot be achieved by latecomers.

More complicated is the issue of international cooperation in the design, development, and shared operation of infrastructure. The space station is to be such a cooperative venture among the European Space Agency, Canada, Japan, and the United States. The issues of concern for the United States in this area are:

- The distribution of operating costs and facilities among the partners;

- The fear that international partners will reap economic gain by investing in using the space station in areas like materials processing while the United States continues to invest in infrastructure; and

- The need to reconcile the budget process and U.S. commitments to joint ventures with its allies.

The first two issues are under consideration at NASA. The Congress's direction to NASA continues to stress the themes of shared costs and preparation to take early advantage of the nation's investment in a space station by supporting science applications programs. The growing maturity of both the European Space Agency and Japan in space technology has led to significant commitments to future infrastructure investment in manned and unmanned transportation systems and space platforms. During the 1990s, the European Space Agency programs will probably experience the same pressures of simultaneously supporting costly infrastructure projects and smaller applications and scientific missions that are present in the U.S. program. The United States will, therefore, not be the only partner to deal with this problem.

The need to harmonize the budget process and the negotiation of international partnerships such as the space station is evident. On the one hand, the United States suffers a loss of prestige when the Administration negotiates agreements to which the Congress is not fully committed. On the other hand, it is questionable whether international negotiations should be a factor in the Congress's decision to commit itself to a program that it has yet to accept on its own merits. One possibility is to refrain from international negotiations on joint ventures until the Congress has appropriated a significant portion of funding for a project. In the case of projects like the space station, the authorization for international negotiations could be tied to advance appropriations included by the Administration in the fiscal year 1989 budget request.

The scale of enterprises like a Mars mission or establishing a lunar base has led a number of people to suggest cooperative ventures with the Soviet Union. The rationale supporting such efforts is similar to that supporting any cooperative scientific venture, but with significant caveats. National security considerations are present with regard to the transfer of technology. The leadership factor cuts in two ways in such a venture. Accomplishment would be shared between the contending political systems, but sustaining the cooperation necessary to undertake a Mars mission or establish a lunar base would bestow leadership benefits on all parties. The complexity of U.S.-Soviet relations opens the possibility of cooperative ventures being set back at any time. Thus, strategies that call for separate but coordinated activities may be preferable, even though they will limit the cost-sharing aspect of any venture.

Cooperation Between Government Agencies

The history of cooperation between different government agencies in space policy is mixed.1/ NASA and the Department of Defense have alternated between cooperative and competitive relations. NASA and the National Oceanic and Atmospheric Administration cooperated in developing and operating the civil weather satellites system and, until 1983, the land remote sensing system. Recently, as interest in space applications has grown, other federal agencies have become involved in space policy, most notably the Department of Transportation in the regulation of private-sector launch companies, and the Department of Commerce in the more general promotion of commercial activities. This broadening of concern about space policy has, at times, led to disagreements about authority and responsibility. In the context of the effectiveness of NASA spending, the relationship with the Department of Defense remains the most critical.

The failure of the pre-Challenger shuttle-only space transportation policy should not obscure the rationale for coordination of Department of Defense and NASA space transportation policy and planning. The NASA core program is dominated by space transportation investment and operations. To the extent that expenditures are duplicated by or not coordinated with Department of Defense space transportation investment and operation, the effectiveness of civil space spending will be decreased. In its most evolved form, coordination could include the joint development of Earth-to-orbit transportation systems, and a combined national space transportation strategy that stresses efficient use and operation of federally developed and operated space transportation.

Budget Process Issues

A basic tension between the budget process and the civil space program is the annual appropriation cycle and the many years it takes to develop and build a system like the shuttle or the space station. NASA, the system developer, tries to devise a plan that completes its project in a cost-effective way that can be incorporated into the agen-

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1. Recent issues are presented and discussed in Erasmus H. Kolman, *What Future for the United States in Space?* (September 1987), an occasional paper for the National Aeronautics and Space Administration, National Academy of Public Administration.

cy's longer-term budget plan. The Congress is concerned not only with the effectiveness of the NASA program, but also with the larger issue of fiscal and budgetary policy as a whole.

While the effectiveness of the NASA program may be enhanced by advance or multiyear appropriations, such appropriations may limit the Congress's flexibility in addressing larger budgetary issues by implicitly broadening the scope of expenditures that cannot be deferred or canceled at any point in time. Moreover, to the extent that a particular project within an agency, or an agency as a whole, establishes a special status granted by advance appropriations, the project or agency receives an implicit and unintended priority when larger fiscal problems lead the Congress to enact across-the-board spending cuts as required by the Balanced Budget and Emergency Deficit Control Reaffirmation Act of 1987 (Public Law 100-119) or as negotiated at the end of 1987.

The case for multiyear appropriations is usually made in terms of the efficiencies planners gain by having a stable budget outlook rather than having to "game" the appropriations process.2/ If insufficient funds are available to support an optimal schedule, the quality of the project may suffer, or its cost may increase. If more funds than necessary are appropriated, federal outlays may be higher than necessary and inefficiencies encouraged within the project. This argument is more forceful during a construction phase of a project than during its design, and it depends, in large part, on the ability of NASA to estimate accurately the cost of a mission.

Two additional arguments support multiyear appropriations for major NASA programs. First, in those projects where international partnerships are undertaken, advance funding commitments would enhance U.S. credibility and reliability as a partner. Such improvements in the U.S. image may be increasingly important, because the traditional allies have a widening set of choices, including partnership with the Soviet Union, or among themselves. Second, as the funding required by the core program illustrates, the NASA program has been

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2. A different case for multiyear appropriations is made for production programs. In these programs, the argument is that reductions in unit cost are lost when the number of units procured is cut back, since the cost of capital facilities and other fixed costs are spread over fewer units. See Congressional Budget Office, *Effects of Weapons Procurement Stretch-Outs on Costs and Schedules* (November 1987).

characterized by many new starts that will require increased outlays in the future. Full funding for larger projects could generate a greater awareness in the Congress of the implications of apparently small new starts for future agencywide funding requirements.

Broadening Private-Sector Involvement in Space

The debate concerning the space station, and the cost of building and operating the low-Earth-orbit infrastructure more generally, has included the argument that the federal government, principally NASA, should step aside and encourage direct private investment in space infrastructure. In its simplest form, the argument holds that NASA is an engineering bureaucracy that inefficiently designs and operates space infrastructure, at least where commercial users are concerned. NASA designers pursue the objective of the broadest possible capability at the expense of lower cost for a basic capability that would satisfy the majority of users, but not all possible users. As a consequence, the cost of getting into, and then operating in, space is much higher than it need be. Encouraging private investment in, and subsequent operation of, space infrastructure would lower these costs, according to this argument. Moreover, the federal government could get out from under the cost of building and then maintaining idle space infrastructure capacity by substituting service purchases and leasing arrangements for direct ownership and operation.

Advocates of increasing the private sector's ownership of space infrastructure contend that the consequences of NASA's ineffectiveness in the infrastructure area extend beyond just higher costs for the federal program. They argue that, by not permitting the cost of space activity to fall, a flood of viable commercial ventures--from space manufacturing to tourism--is held back. These commercial ventures would contribute to U.S. economic growth, and initiate a positive circle of increased space commercial activity and cost reduc-tion, since economies of scale would be realized in the transportation and on-orbit infrastructure that are necessary to meet the growing demand for space activity. For some observers, one desirable outcome of unleashing the private sector in this way would be to redirect NASA's effort away from the mundane business of operating transportation and on-orbit laboratory facilities toward the more exciting prospects of scientific exploration and discovery.

The central premises of the argument that broadening private-sector investment in space activity would energize the entire national effort deserve careful examination. If the private sector, freed of NASA's allegedly burdensome oversight, failed to develop space infrastructure more cheaply and effectively, then federal programs providing special incentives to private infrastructure investment might be necessary, leading to a more complicated, and perhaps costly, version, of the current procurement system that already involves private firms in contractual relations with NASA. If a flood of new marketable uses of the space environment proved not to be awaiting the spur of lower operating costs, then the government would remain the dominant user of space infrastructure, and economies of scale would not be forthcoming unless the government were to expand its activities.

There is little clear evidence that the private sector can in all cases design and undertake infrastructure investment more cheaply than NASA. The case against significant private-sector savings is stronger to the extent that the project involved includes sizable technical risk and retains an aspect of a research and development effort throughout its life. (For example, at what point does the shuttle system stop being a system in development and become an operating concern?) The private sector is more likely to provide lower costs if the technology is mature and well understood, as in the case of expendable launch vehicles.

The level of interdependence among missions and infrastructure elements requires a careful consideration of how privately provided infrastructure could be integrated with the other activities of the federal program. As the hiatus in shuttle flights has shown, the ripple effect of failure in a key element can extend, with tremendous costs, beyond the part of the program directly effected.

The second major premise of the larger role for the private sector in infrastructure is less supportable. Reviews of potential commercial uses of space tend to agree that such uses await additional basic research, an area where government support, directly through scientific research and indirectly through cost sharing, is critical.3/ Most of the private-sector interest in commercial activity in space remains in the mature satellite communications industry and in providing the capability to get to space and function there, rather than in delivering a good or a service to the marketplace. Unless a commercial demand exists for these space-based products and services, there will be no demand for the inputs necessary to produce them. Thus, even where costs may be lowered, it is unlikely that a flood of new commercial ventures will occur during the next decade.

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3. For example, most reviews of the application of the microgravity environment in drug or electronic materials manufacturing suggest near-term prospects are not significant. See National Research Council, *Industrial Applications of the Microgravity Environment* (Washington, D.C.: National Academy Press, May 1988).

SPACE ACTIVITIES OF THE UNITED STATES, SOVIET UNION AND OTHER LAUNCHING COUNTRIES/ORGANIZATIONS: 1957-1989

TABLE OF CONTENTS

INTRODUCTION 1
  SUMMARY OF ACTIVITIES IN 1989 2
    United States: Back on Track 2
      President Bush's New Space Policy 2
      Cape York, Soviet, and Chinese Launch Services 3
    Soviet Union: *Glasnost*, *Perestroika* and the Soviet Space Program 4
      There Was a Moon Race 5
      Soviet Space Budget 5
      Program Highlights in 1989 5
    China, Europe, Japan, India and Israel 7
  STATISTICAL DATA ON LAUNCHES: 1957-1989 7

PART ONE: U.S. AND U.S.S.R. SPACE ACTIVITIES 12
CHAPTER 1: EARLY HISTORY 12
CHAPTER 2: HUMAN SPACEFLIGHT 13
  SHOOTING FOR THE MOON 13
    Early Flights: 1961-1966 13
    1967: Double Tragedies 14
    The United States Wins the Moon Race 14
  DETENTE IN SPACE: THE APOLLO-SOYUZ TEST PROJECT (ASTP) 15
  SPACE STATIONS 15
    Soviet Space Stations 15
      The First Generation: Salyut 1-5 15
      The Second Generation: Salyut 6 and 7 17
      Third Generation: Mir ("Peace") 19
        1986-1987 20
        1988-1989 21
    U.S. Space Stations 22
      Skylab 22
      The U.S./International Space Station "Freedom" 22
    Future Space Stations 23
  REUSABLE SPACE VEHICLES 24
    The U.S. Space Shuttle 24
      The Challenger Tragedy 24
      Pre-Challenger Shuttle Missions 25
      Return to Flight 26
    Aerospace Plane 26
    Soviet Space Shuttle 27

CHAPTER 3: SPACE APPLICATION FLIGHTS 41
  COMMUNICATIONS 41
  NAVIGATION 43
  GEODESY AND MAPPING 43
  SEARCH AND RESCUE 44
  METEOROLOGICAL SATELLITES 44
  REMOTE SENSING 44
  MISSION TO PLANET EARTH 46
CHAPTER 4: SPACE SCIENCE 48
  EARTH-ORBITAL SPACE SCIENCE 48
  AUTOMATED LUNAR EXPLORATION 49
  U.S. PLANETARY MISSIONS 51
  SOVIET PLANETARY MISSIONS 52
  FUTURE U.S. AND SOVIET SPACE SCIENCE MISSIONS 54

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CHAPTER 5: MILITARY SPACE ACTIVITIES 56
MILITARY VERSUS CIVIL SPACE MISSIONS 56
MILITARY SPACE PROGRAMS 56
SPACE WEAPONS 59
Early U.S. and Soviet Antisatellite Programs 59
The Soviet Co-Orbital ASAT Device 59
U.S. F-15 ASAT Device 60
Other Antisatellite Devices 61
Soviet Fractional Orbital Bombardment System (FOBS) 61
CONCERNS ABOUT THE MILITARIZATION OF SPACE AND "STAR WARS" 61
CHAPTER 6: SPACE PROGRAM MANAGEMENT AND RESOURCES 63
SPACE EXPENDITURES OF THE U.S. AND U.S.S.R. 63
MANAGEMENT OF SPACE PROGRAMS 63
LAUNCH SITES 64
LAUNCH VEHICLES 65
CHAPTER 7: FUTURE DIRECTIONS 70
THE NATIONAL COMMISSION ON SPACE AND RIDE REPORTS 70
Pioneering the Space Frontier 70
Leadership and America's Future in Space 72
PRESIDENT BUSH'S "HUMAN EXPLORATION INITIATIVE" . . . 73
LONG-TERM SOVIET PLANS 73
COOPERATION BETWEEN THE UNITED STATES AND SOVIET UNION 74
CHAPTER 8: TABLE OF SPACE "FIRSTS"--U.S. AND SOVIET 77

PART TWO: SPACE ACTIVITIES OF OTHER LAUNCHING COUNTRIES/ORGANIZATIONS 82
CHAPTER 1: CHINA 83
CHAPTER 2: EUROPEAN SPACE AGENCY AND ARIANESPACE . . 87
CHAPTER 3: INDIA 92
CHAPTER 4: ISRAEL 94
CHAPTER 5: JAPAN 95

SPACE ACTIVITIES OF THE UNITED STATES, SOVIET UNION AND OTHER LAUNCHING COUNTRIES/ORGANIZATIONS: 1957-1989

INTRODUCTION

During the first era of space activities, only the United States and the Soviet Union had the ability to place satellites in Earth orbit or send them off to distant planets. As early as 1965, this monopoly was challenged by France, but the launch vehicle it developed could only orbit very small payloads, and its use ended ten years later. Britain also developed its own launch vehicle, but it was used only twice. Both Britain and France later joined with nine other European countries to form the European Space Agency, which now has a launch vehicle called Ariane. Four other countries--China, India, Israel, and Japan--also have independent launch capabilities.

The purpose of this report is to summarize the programs of the United States, Soviet Union, and the other "launching" countries. Launches by commercial companies are included with the country where the company is headquartered, except for Arianespace (a French company) which is addressed here together with ESA. A statistical summary of launches and payloads since 1957 is shown in tables 1 and 2.

CRS has prepared several other reports on space activities which the reader may wish to consult for further information. A series of studies entitled *Soviet Space Programs* has been prepared for the Senate since the early 1960s. The most recent edition, covering 1981-1987, is available from the Senate Commerce, Science and Transportation Committee. *United States Civilian Space Programs 1958-1978 (Volumes I and II)* was written for and published by the House Science and Technology Committee in 1981 and 1983. *World-Wide Space Activities*, which provides detailed information on the space activities of all countries in the world except the United States and Soviet Union, was prepared for and published by the House Science and Technology Committee in 1977. CRS Report 84-127, *Space Activities of the Non-Launching Countries*, updates information on countries which use space but do not have an indigenous launch capability. Several CRS issue briefs are also available on specific space topics and are referenced herein.

This report has been revised and updated by Marcia S. Smith, Specialist in Aerospace Policy. Mr. Geoffrey Perry, M.B.E., head of the Kettering Group in England, provided some of the data for the tables and other information. The report is based on analysis of information contained in the numerous, unclassified sources cited in the above committee prints, and on earlier editions of this report written by the late Charles S. Sheldon II, formerly a Senior Specialist in Space and Transportation. Detailed citations are omitted for the purpose of keeping this as brief as possible. The most frequently used sources, however, are publications of the Foreign Broadcast Information Service (FBIS) and trade publications such as *Aviation Week and Space Technology* and *Aerospace Daily*.

SUMMARY OF ACTIVITIES IN 1989

As shown in table 1a, the total number of launches in the world during 1989 declined to 101, the least for a single year since 1964. Part of the reason was that three launching countries--China, India and Israel--had no launches in 1989, but more noteworthy was the reduction in the number of Soviet launches, from 90 to 74. The chief reason for the reduction in Soviet launches probably was increased satellite lifetimes, meaning that individual spacecraft do not have to be replaced as often.

The United States completed 18 launches, the most in a single year since 1985, demonstrating that it has finally recovered from the failures of 1986. Japan and Europe maintained the same launch rate (two and seven, respectively) as in 1988.

United States: Back on Track

During 1989, there were 18 U.S. launches, the most since the triple launch vehicle failures of 1986 (the space shuttle, Titan and Delta). Among the launches were five of the space shuttle, as NASA begins to build up to a launch rate of 12-14 per year (approximately half of what had been planned prior to the 1986 *Challenger* tragedy). In the future, the shuttle will be used primarily for missions that require the presence of a crew or the unique capabilities of the shuttle, rather than simply as a "truck" taking satellites to orbit. During the current phase of catching up on the backlog of satellites awaiting launch, however, the shuttle is still being used mostly in the "truck" mode, and that was the primary mission for each of the five 1989 shuttle launches.

Department of Defense (DOD) satellites accounted for 2 of the shuttle missions, and 11 of the other U.S. launches in 1989. Five of the DOD launches orbited Navstar Global Positioning System (GPS) navigation satellites. Eighteen GPS satellites are needed for a complete system, and DOD hopes to have Navstar GPS operational in 1992. Other DOD satellites reportedly were for reconnaissance, early warning, and the Strategic Defense Initiative Organization.

Space science did well in 1989, with the encounter of Neptune by the Voyager 2 spacecraft (launched in 1977), the launch of two new planetary probes (Magellan to Venus, and Galileo to Jupiter), and the launch of an earth-orbiting spacecraft (COBE, the Cosmic Background Explorer) that is studying the origin of the universe.

President Bush's New Space Policy

Perhaps the most significant action in the U.S. space program in 1989 was not the launch of a satellite, but the announcement by President Bush of long-term goals for the space program. On July 20, 1989, the 20th anniversary of the first Apollo landing on the Moon, President Bush made a major space policy address in which he announced that the United States would return humans to the Moon and then go on to Mars in the 21st Century. Although the speech was criticized for lacking a timetable and funding requirements, it did satisfy many members of the space community who had been calling for such a Presidential endorsement of long-term goals. The debate over the President's goal, now called the Human Exploration Initiative (HEI), will likely begin in earnest during 1990 (see part 1, chapter 7).

Other space policy issues during 1989 were the future of the Landsat land remote sensing satellite system and the National Aero-Space Plane (NASP) program. In each case, the re-created National Space Council, chaired by Vice President Quayle, stepped in to resolve funding issues within and between the agencies supporting (or not supporting) these programs. Other major issues were support for NASA's space station *Freedom* program as NASA stretched out the assembly phase by two years (see part 1, chapter 2), and the controversy over whether U.S.-made satellites should be launched on Soviet and/or Chinese launch vehicles.

Cape York, Soviet, and Chinese Launch Services

The latter issue promises to be controversial during 1990. With regard to launching U.S.-made satellites on Soviet launch vehicles, discussion centers on two factors: technology transfer implications of Soviet access to U.S. satellites prior to launch, and trade implications of the entry of presumably low-priced Soviet launch services into the launch services market. U.S. policy currently prohibits the export of satellites with American components to the Soviet Union for launch because of technology transfer concerns. A U.S. company, Space Commerce Corp. (SCC), is marketing Soviet launch vehicle services in the hope that the U.S. position will change, however. SCC signed a contract with an American company, Energetics, in 1989 for launches of secondary payloads on Soviet Proton rockets. Whether an export license will be granted remains unclear.

To avoid technology transfer concerns, an Australian company, Cape York Space Agency (CYSA), has proposed purchasing Soviet-built rockets and launching them from a new launch site that would be built at Cape York, Australia. The rockets would be owned by CYSA, and satellites would be integrated onto the rockets by Australians or Americans (a U.S. company, U.S. Space Boosters, Inc., has shown interest in managing the launch site). Australian officials assert that no Soviets need to be at the launch site at all. If these arrangements were to satisfy technology transfer concerns, the issue of how much CYSA would charge per launch, and if fair trade practices were followed, would remain. U.S. Space Boosters, Inc. (USBI, a division of United Technologies) has applied to the U.S. State Department for a Technical Assistance Agreement to permit it to work with CYSA. The State Department is considering the matter, but strong objections have been raised by U.S. commercial launch services companies because of concern of unfair competition. Three U.S. companies--General Dynamics, McDonnell Douglas, and Martin Marietta--are offering commercial launch services in competition with Europe's Arianespace. These companies are concerned that Soviet (and Chinese) launch service providers would offer substantially lower prices and undercut their market.

In the case of Chinese launches, the concern has been less technology transfer and more trade implications. In 1988, however, the Reagan Administration approved export licenses for three U.S.-made satellites to be launched on Chinese launch vehicles after the Chinese made certain concessions (see part 2, chapter 1). The first satellite, Asiasat, is currently scheduled for launch in April 1990. The other two, AUSSAT 1 and 2, are still under construction and planned for launch in 1991 and 1992 respectively. Asiasat is owned by Asiasat Inc., a partnership of British, Hong Kong and Chinese interests. AUSSAT 1 and 2 are Australian.

Following the June 1989 uprising in Tiananmen Square, however, President Bush suspended the export licenses for the three satellites (and other items on the Munitions Control List). In December, he lifted the suspensions on the basis that the launches were in the U.S. national interest. The President's decision was controversial and Congress is expected to remain deeply interested in this issue. The Administration had made it clear that future export licenses will be reviewed on a case-by-case basis.

Soviet Union: *Glasnost*, *Perestroika* and the Soviet Space Program

The reduction in launches by the Soviet Union in 1989 can probably be traced most directly to increased satellite lifetimes, meaning that existing satellites can be replaced less frequently. During the year, however, other forces began to shape the Soviet space program that may result in even fewer launches in the next several years.

Most important of these forces are President Gorbachev's *perestroika* (restructuring) and *glasnost* (openness) policies. For the first time, the Soviet space program is under public attack for being a poor investment of Soviet resources. Some prominent Soviet politicians, notably Boris Yeltsin, have cited the space program as a prime example of wasted Government effort, and journalists are openly challenging Soviet space officials about the value of the space program to the average Soviet citizen. While the level of public antipathy to the space program is difficult to estimate, space program officials are now on the defensive.

What effect *glasnost* and *perestroika* will ultimately have on the Soviet space program clearly cannot be determined now. Space program advocates may be successful in convincing the Soviet public that investing in space augments the Soviet economy, or they could fail, and be forced to narrow their goals and objectives. Among the most vulnerable programs is the Soviet space shuttle, Buran, and its Energiya launch vehicle, which even space advocates have had a difficult time justifying. The next flight of Buran has been delayed until 1991 and, like the first flight in 1988, is not expected to carry a crew. When the system is operational, the Soviets plan to fly it only once a year, making it difficult to understand where it will fit into the overall space program. The Energiya launch vehicle, similar in capability to the U.S. Saturn V that sent astronauts to the Moon, seems to have little mission justification other than launching Buran. Thus, while the Soviets may have considerable launch capability, they do not seem to need it in the near term.

There Was a Moon Race

Glasnost was rampant in the Soviet space program this year. Among the more notable revelations were discussions by space veterans of Soviet plans to send cosmonauts to the Moon in the 1960s during the "Moon Race" era. Although Soviet space officials asserted during the early 1960s that they intended to send cosmonauts to the Moon in competition with the United States, prompting the "Moon Race," once the United States landed astronauts there in 1969, the official Soviet position changed to one of denial that they ever had such plans. Now, interviews with Soviets in key positions at that time have confirmed that they were hoping to send cosmonauts to the Moon, but could not because their effort to build a Saturn V-class launch vehicle failed. Details on the testing of the launch vehicle, designated N-1 in the Soviet Union but known in the West as the G booster, were provided by the man who headed the design bureau at the time. Subsequently, a delegation from the Massachusetts Institute of Technology was shown test spacecraft designed as part of the lunar program. One of the cosmonauts selected to be part of the first lunar mission, Valeriy Bykovskiy, published a book in which he discussed Soviet lunar plans, too.

Soviet Space Budget

Also, the Soviets finally published information on how much they spend on their space program, although the figures were discounted in the West because they were so much lower than Western estimates. The Soviets state that they spend $11 billion per year on space, of which $6.2 billion is for military space activities, $2 billion is for the Energiya/Buran program (their space shuttle and heavy lift launch vehicle), and the rest ($2.8 billion) for other non-military space programs. Western estimates for years have assumed that the Soviets spend approximately 1.5 times as much as the United States on space, which would make the figure about $45 billion. The wide disparity between Western estimates and the Soviet figures may be the result of differences in what is included in the number (the Soviets may not include procurement and operations, for example).

Program Highlights in 1989

In terms of the Soviet space program programmatically, the most interesting events of 1989 were the "deoccupying" of the Mir space station between April and September, the launch of Kvant 2, the launch of an American commercial experiment performed on Mir, the lack of RORSAT launches, and the launch of two earth-orbital space science missions.

Since 1987, it had appeared that the Soviets would maintain a crew aboard their space station Mir at all times, thereby achieving permanent occupancy. At the beginning of 1989, the Soviets stated that a crew would be launched in April to replace the cosmonauts then aboard the space station, but as the launch day approached, the Soviets announced that no replacement crew would be sent to Mir. They said at the time, and a Soviet cosmonaut has confirmed, that the problem was technical difficulties which delayed the launch of two modules that were to be docked with Mir. The modules contained equipment and experiments for the crew to use, and without the modules, there would have been little to occupy the crew's time. Western reports that the decision was budget related seem to have little basis in fact, but the Soviets (now attempting to justify their program to the Soviet people) picked up on this approach and subsequently discussed how many rubles were saved because of the months Mir was vacant.

A new crew was launched to Mir in September, and one of the two modules docked with the space station in December. Designated Kvant 2, it is a special airlock to make it easier for the cosmonauts to exit the station and also contained backpacks to allow the cosmonauts to work more freely in space (see part 1, chapter 2). The cosmonauts made 5 spacewalks, two of them using the backpacks, in January and February 1990. One of the three Progress cargo ships that visited Mir in 1989 carried an experiment developed by a U.S. company, Payload Systems Inc., as a commercial payload. A new version of the Progress vehicle was introduced in 1989, designated Progress M, with greater capabilities.

In other space program areas, it was significant that there were no launches of nuclear reactor-powered Soviet radar ocean reconnaissance satellites (RORSATs). The last RORSAT launch was in March 1988. The next month, communication was lost with a previously launched RORSAT (Cosmos 1900) and the Soviets waited tensely until October of that year to see if fail-safe systems aboard the satellite would correctly send the nuclear reactor section to the higher "safe" orbit used for these devices. The fail safe systems worked, but the Soviets apparently have decided to reassess the design of (and perhaps the need for) these satellites. This was the third failure in the RORSAT program (the other two were Cosmos 954 in 1978 and Cosmos 1402 in 1983). The U.S. Department of Defense has cited RORSATs as a primary justification for building an antisatellite (ASAT) weapon (see part 1, chapter 5).

Soviet space science did well in 1989, with the launch of two major missions. First was Activniy, a pair of satellites (one Soviet, one Czechoslovakian) for studying solar-terrestrial interactions. The Soviets have said little about this mission since launch, however, calling into question its success. The second major mission was the launch of the Granat astronomical satellite for x-ray and gamma ray observations. The launch had been delayed from 1988.

China, Europe, Japan, India and Israel

There were no Chinese launches in 1989, and the major policy issue was whether or not to allow U.S. satellites to be launched on Chinese launch vehicles following the Tiananmen Square uprising (see above). Europe's Arianespace conducted seven launches, primarily of communications satellites for European and other customers. Arianespace also launched one European weather satellite (MOP), and the Hipparchos astronomical observatory. A malfunction left Hipparchos in an improper orbit, but scientists are gaining useful data from the satellite.

Japan had a quiet year, with only two launches, one a weather satellite and the other for astronomical observations (Exos-D). For technical reasons, the Japanese have slipped the expected first launch date of the H-2 rocket to 1993 (from 1992). A major policy issue developed during the year when the U.S. Trade Representative (USTR) filed a "Super 301" unfair trading practice action against Japan. Among the complaints is that Japan has closed its communications satellite market to U.S. competition. The issue remains unresolved between the two countries.

India and Israel made no launches in 1989.

STATISTICAL DATA ON LAUNCHES: 1957-1989

The following tables provide data on total launch successes and failures and payload successes for all countries, and types of payloads launched by the United States and Soviet Union, from 1957 to the present. Footnotes explain some of the cautions to be observed in using the tables. For example, launch "success" indicates only that a payload achieved orbit, even if it did not achieve the intended orbit.

CRS-7

TABLE 1a. World-Wide Record of Successful Space Launches

Year	USSR	US	CHINA	JAPAN	ESA	INDIA	ISRAEL	*FRANCE**	*AUST.**	*UK**	TOTAL
1957	2										2
1958	1	5									6
1959	3	10									13
1960	3	16									19
1961	6	29									35
1962	20	52									72
1963	17	38									55
1964	30	57									87
1965	48	63						*1*			112
1966	44	73						*1*			118
1967	66	58						*2*	*1*		127
1968	74	45									119
1969	70	40									110
1970	81	29	1	1				*2*			114
1971	83	32	1	2				*1*		*1*	120
1972	74	31		1							106
1973	86	23									109
1974	81	24		1							106
1975	89	28	3	2				*3*			125
1976	99	26	2	1							128
1977	98	24		2							124
1978	88	32	1	3							124
1979	87	16		2	1						106
1980	89	13		2		1					105
1981	98	18	1	3	2	1					123
1982	101	18	1	1							121
1983	98	22	1	3	2	1					127
1984	97	22	3	3	4						129
1985	97	17	1	2	3						120
1986	91	6	2	2	2						103
1987	95	8	2	3	2						110
1988	90	12	4	2	7		1				116
1989	74	18		2	7						101
TOTAL	2,180	905	23	38	30	3	1	*10*	*1*	*1*	3,192

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* Note that France, Australia and the United Kingdom no longer launch their own satellites. France and the UK are members of the European Space Agency (ESA) which built the Ariane launch vehicle whose first launch was in 1979.

Italy conducted eight launches from 1967 to 1975, and one in 1988, using U.S. Scout rockets from the San Marco platform off the coast of Kenya. Since the launch vehicles were American, NASA includes them in U.S. launch statistics and they are treated the same way here.

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CRS-8

TABLE 1b. World-Wide Record of Known Space Launch Failures

Year	USSR	US	CHINA	JAPAN	ESA	INDIA	ISRAEL	*FRANCE*	*AUST.*	*UK*	TOTAL
1957	*	1									1
1958	*	12									12
1959	*	10									10
1960	2	13									15
1961	*	12									12
1962	*	7									7
1963	*	8									8
1964	*	7									7
1965	*	7									7
1966	*	4		2							6
1967	*	3	*	1							4
1968	*	3	*		1**						4
1969	*	1	1	1	1**						4
1970	*	1	*	1	1**					*1*	4
1971	*	3	*		1**			*1*			5
1972	*	2	*								2
1973	*	2	*					*1*			3
1974	*	1	1								2
1975	2	3	*								5
1976	*		*	1							1
1977	*	2	*								2
1978	*	1	*								1
1979	*		1		1	1					3
1980	*	2	*								2
1981	2	1	*								3
1982	*		*		1						1
1983	1		*								1
1984	*		*								0
1985	1	1	*		1						3
1986	*	3	*		1						4
1987	1	1				1					3
1988	*		*			1					1
1989											0
TOTAL	9*	111	3*	6	8	3	--	*2*	--	*1*	143*

This table shows launches that failed to attain orbit. Where an orbit was achieved, but it was an incorrect orbit that prevented a payload from achieving its mission,the launch is counted as a success, but the payload as a failure.

* It should be noted that both the Soviet Union and China rarely release information on failed launch attempts. In any launch vehicle development program failures can be expected, so it can be reasonably assumed that they have a similar success/failure ratio as the other launching nations.

** ESA, the European Space Agency, was formed in 1975 as the merger of the European Space Research Organization (ESRO) and the European Launcher Development Organization (ELDO). The failures marked with a double asterisk under the ESA heading were part of ELDO's futile attempts to develop the Europa rocket. Those without asterisks are part of ESA's development of Ariane.

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TABLE 1c. World-Wide Summary of Payloads Successfully Launched

Year	USSR	US#	CHINA	JAPAN	ESA	INDIA	ISRAEL	*FRANCE*	*AUST.*	*UK*	TOTAL
1957	2										2
1958	1	5									6
1959	3	10									13
1960	3	17									20
1961	8	35									43
1962	26	59									85
1963	20	62									82
1964	39	73									112
1965	76	97						*1*			174
1966	52	101						*1*			154
1967	75	88						*2*	*1*		166
1968	85	64									149
1969	80	66						*3*			149
1970	103	40	1	1				*1*			146
1971	114	54	1	2						*1*	172
1972	109	42									151
1973	130	26									156
1974	114	28		1							143
1975	140	35	3	2				*4*			184
1976	141	34	2								177
1977	125	29		2							156
1978	142	41	1	3							187
1979	126	18		1	1						146
1980	132	16		1		1					150
1981	148	20	3	3	5	1					180
1982	141	20	1	1							163
1983	138	30	1	3	3	1					176
1984	138	34	2	3	6						183
1985	140	35	1	2	5						183
1986	132	11	2	3	4						152
1987	121	11	2	3	3						140
1988	123	17	4	2	12		1				159
1989	114	25		2	10						151
TOTAL	*3,041	1,243	24	35	49	3	1	*12*	*1*	*1*	4,410

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* Historically, statistics for Soviet payloads have included the orbital platforms used to send payloads into highly elliptical or geostationary orbits, or into planetary trajectories. Devices used by other countries for similar purposes historically have not been counted as extra payloads. A total of 383 platforms are included in the Soviet count. At a later date, they will be subtracted to make the Soviet figures consistent with the other countries.

# The space shuttle is counted as one payload, regardless of what it carries. Satellites deployed from the shuttle are counted as additional payloads if they are left in orbit. Italy's payloads launched from the San Marco Platform are counted in the U.S. total since they were launched with U.S. rockets.

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CRS-10

TABLE 2. Summary of U.S. and Soviet Payloads by Mission*

CATEGORY	UNITED STATES		SOVIET UNION	
	1989	1957-1988	1989	1957-1988
Platforms	–	–	14	369
Earth Orbital Science	3	191	8	189
Automated Lunar/Planetary				
Moon		25		34
Mercury		1		0
Venus		8		33
Mars		9		18
Outer Planets		4		0
Interplanetary Space		8		0**
Applications				
Communications	5	218	11	203
Weather		91	2	65
Geodesy		19	3	28
Earth Resources		7	8	65
Materials Processing		0	1	4
Piloted Activities				
Earth Orbital	5	46	1	71
Earth Orbital (Related)		13	5	100
Lunar		20		0
Lunar (Related)		17		8
Launch Vehicle Tests		11		21
Gen. Engineering Tests		28		4
Reconnaissance				
Photographic		243	23	717
Elint***	2	83	0	115
Ocean Elint		30	3	60
Early Warning	1	43	2	60
Minor Military		43	3	150
Navigation	5	56	9	138
Tactical/Theater Comm.		0	21	419
Weapons-Related				
FOBS***		0		18
Antisatellite Targets		2		18
Antisatellite Interceptors		0		20
Other Military	4	3		0
Total	25	1,218	114	2,927

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* Assignments are arbitrary to some extent and subject to revision each year as more information becomes available. This table is meant to provide only a general level of effort for each country and should be used cautiously.

** The Soviet VEGA probes which visited Venus and later Halley's Comet are included in the Venus total, rather than interplanetary probes.

*** Elint = Electronic Intelligence; FOBS = Fractional Orbital Bombardment System.

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PART ONE

U.S. AND U.S.S.R. SPACE ACTIVITIES

CHAPTER 1

EARLY HISTORY

In 1955 both the United States and the Soviet Union announced their intentions to launch small scientific satellites as a contribution to the International Geophysical Year, a world-wide scientific effort from July 1, 1957, to December 31, 1958, designed to increase understanding of the Earth and of space physics. President Eisenhower, wanting to demonstrate the U.S. commitment to using space for peaceful purposes, initiated Project Vanguard to develop a "civilian" rocket (i.e., not based on missile technology) and a satellite weighing 14 kilograms. He would not allow the Army to launch a satellite even though it had capability to do so in the fall of 1956.

Although it was known that the Soviets were also working on rocket technology, the world was startled when they launched the first satellite, Sputnik 1 (weighing 84 kilograms), on October 4, 1957. Few had expected that the "backward" Soviet Union would beat the scientifically advanced United States in this endeavor, and with a satellite many times heavier than what the United States was planning. Sputnik 2, launched on November 3, 1957, did not help the U.S. image: it weighed 508 kilograms, and carried a live dog, Laika. The first attempt to launch Vanguard, on December 6, 1957, ended in an embarrassing failure when it lifted three feet off the launch pad and came crashing back down in a fiery explosion. President Eisenhower finally relented and allowed the Army to use its missile technology to place an Army satellite (Explorer 1) in orbit on January 31, 1958. Vanguard ultimately succeeded in placing a satellite in orbit on March 17, 1958 These early satellites were designed simply to prove the principles of spaceflight, although scientists were able to extract useful information, too. For example, the early Explorer satellites led to discovery of the Van Allen belts of radiation which encircle the Earth.

CHAPTER 2

HUMAN SPACEFLIGHT

SHOOTING FOR THE MOON

Early Flights: 1961-1966

On April 12, 1961, Yuriy Gagarin became the first human to travel in space as he made one orbit of the Earth in Vostok 1. On May 5, Alan Shepard became the first American in space, although his Mercury-Redstone 3 (Freedom 7) flight was suborbital, lasting for only 15 minutes and landing about 480 kilometers downrange from Cape Canaveral.

Shepard's flight, even though it was suborbital, gave President Kennedy the confidence he needed to appear before Congress three weeks later, on May 25, 1961, to call upon the Nation to commit itself to the goal of landing a man on the Moon and returning him safely to Earth by the end of the decade. America accepted the challenge and the "Moon Race" was on, even though it was not until nine months later, on February 20, 1962, that John Glenn became the first U.S. astronaut to orbit the Earth.

The Soviet Vostok and U.S. Mercury flights were similar in purpose, and each country launched a total of six missions in their respective series. The flights demonstrated that humans could travel into space and return to Earth safely. The last of the Vostok flights took the first woman, Valentina Tereshkova, into space.

The Soviet Union followed its Vostok series with two flights of a modified version of that spacecraft, called Voskhod. On October 1964, Voskhod 1 carried the first three-man crew, and in March 1965, the Voskhod 2 mission included the first extravehicular activity (EVA) or spacewalk. The United States moved out quickly with the Gemini program in which 10 flights were conducted from 1965-1966 to increase the duration of the missions (up to 14 days), develop experience in rendezvous and docking procedures, and increase experience with EVAs (the first U.S. spacewalk occurred in June 1965).

While the United States conducted the Gemini flights, no Soviet piloted flights were made, and skepticism developed as to whether the two countries were in a race to the Moon or not. Since the Soviets conducted their space program secretively, it was difficult to determine their plans definitively, so accounts of Soviet planning relied on Western analysis and speculation. In 1989, however, the Soviets finally conceded that they had, in fact, intended to send cosmonauts to the Moon in the 1960s, but were unable to develop a Saturn V-class launch vehicle. An interview with the man in charge of the design bureau for the launch vehicle, designated "N-1" by the Soviets but more widely known in the West as the "G" vehicle, confirmed Western reports that the vehicle had failed in its four launch attempts between 1969 and 1972. Also, members of a delegation from the Massachusetts Institute of Technology visiting the Soviet Union in 1989 were shown test spacecraft designed as part of the lunar landing program, and a book was published by cosmonaut Valeriy Bykovskiy in which he stated that he was to have been one of the two cosmonauts on the first lunar mission.

1967: Double Tragedies

In 1967, both countries were ready to introduce new piloted space vehicles--Apollo for the United States; Soyuz for the Soviet Union. The first missions for both of these vehicles ended in tragedy.

On January 27, 1967, the three-man crew of what was to have been the first Apollo flight--Gus Grissom, Ed White, and Roger Chaffee--were killed when a fire erupted in their Apollo spacecraft during pre-launch tests. Three months later, on April 24, 1967, Vladimir Komarov was killed in the first Soyuz flight when the craft's parachute lines became tangled during descent; he was killed upon impact with the Earth. Both programs were set back for a year and a half as they responded to safety concerns raised by the separate accidents.

The United States Wins the Moon Race

When the programs resumed in October 1968, it was clear that the United States was ahead in the Moon Race. The first U.S. flight (Apollo 7) was a full scale test of the Apollo command module in Earth orbit. The first Soviet flight (Soyuz 2 and 3) was a simple rendezvous between a piloted and an automated spacecraft, something that had been accomplished repeatedly in the U.S. Gemini program. In December 1968, three U.S. astronauts--Frank Borman, Jim Lovell, and Bill Anders--spent Christmas in lunar orbit. Their flight had been made possible by development of a special launch vehicle, the Saturn V, which was used to launch all the Apollo lunar missions. As noted earlier, Soviet attempts to develop a Saturn V-class launch vehicle failed during the 1960s and 1970s. The new Soviet Energiya launch vehicle, first tested in 1987, is a Saturn V-class vehicle (see chapter 6).

On July 20, 1969, the United States officially won the Moon Race when Neil Armstrong and "Buzz" Aldrin became the first humans to set foot on the lunar surface, while Mike Collins orbited overhead. Through 1972, five more U.S. crews set foot on the lunar surface (Apollo 12, 14, 15, 16 and 17) returning 380 kilograms of lunar material to Earth for analysis. A sixth attempt, Apollo 13 in 1970, narrowly averted tragedy when the crew safely returned to Earth after an explosion in the service module.

Meanwhile, the Soviet Union continued a few automated flights to develop hardware for a human lunar mission (Zond 4-8 from 1968 to 1970, and apparently four Cosmos flights in 1970-1971), but lacking a launch vehicle with sufficient capability, they were unable to send people to the Moon and still have not done so, although they have retrieved lunar samples with automated probes.

Instead, they turned their attention to Earth orbit. In January 1969 they accomplished the first docking of two piloted ships (Soyuz 4 and 5) permitting crew transfer using EVA. Soyuz 6, 7, and 8 in October 1969 made a group co-orbital flight, although it is thought that two of the ships (Soyuz 7 and 8) were supposed to dock, but were unable to do so. In 1970, Soyuz 9 set what was then a duration record of 18 days. From that point, the Soviets began their very successful space station program described below.

DETENTE IN SPACE: THE APOLLO-SOYUZ TEST PROJECT (ASTP)

As a contribution toward detente, and as a spur to the development of a universal, androgynous docking system which would allow each country to rescue the other's astronauts, the United States and Soviet Union agreed to work cooperatively to conduct a joint flight, called the Apollo-Soyuz Test Project (ASTP), in which a three-man Apollo crew docked with a two-man Soyuz crew in 1975.

The Soviet Union agreed to a few modifications of the Soyuz spacecraft to permit this docking, and a test flight (Soyuz 16) was conducted in 1974. Both countries launched their ASTP spacecraft on July 15, 1975; the Soviet flight was designated Soyuz 19, while the U.S. flight has always been referred to simply as ASTP. The two ships docked on July 17, and undocked on July 19 after two days of exchange visits and joint experiments. Soyuz 19 returned to Earth on July 21; ASTP landed on July 24. Since ASTP was the last flight for the Apollo spacecraft, the androgenous docking adaptor became obsolete at the end of the mission.

SPACE STATIONS

Soviet Space Stations

The First Generation: Salyut 1-5

The world's first space station, Salyut 1, was placed in orbit by the Soviet Union on April 19, 1971. When docked with a Soyuz, it had about 100 cubic meters of interior space, compared to 275 cubic meters in the American Skylab space station (without the Apollo spacecraft).

The first attempt to occupy the space station failed when the Soyuz 10 crew was unable to enter the station after successfully docking with it. The Soviets then launched the three-man Soyuz 11 crew which became the first space station crew. They spent 24 days conducting medical, Earth resources, and astronomical experiments. Tragically, the crew was killed during their return to Earth on June 29, 1971. They had improperly closed a valve between two sections of the Soyuz spacecraft, and when the sections separated during reentry, the spacecraft's atmosphere vented into space. The Soviets had long since given up the practice of requiring crews to wear spacesuits because of confidence in their hardware, so the three men--Georgiy Dobrovolskiy, Vladislav Volkov and Viktor Patsayev--were asphyxiated. Since this flight, all Soviet cosmonauts have been required to wear spacesuits during launch and reentry, and because the original Soyuz was unable to accommodate three space-suited crew members, the Soviets launched only two-man crews for the next ten years until the redesigned Soyuz T came into use.

The next two space station launches, Salyut 2 and Cosmos 557 in 1973, were failures. They were followed by two free-flying Soyuz missions (Soyuz 12, a diagnostic flight following the Soyuz 11 tragedy, and Soyuz 13, a piloted astronomical observatory).

Finally, in June 1974, the Soviets successfully orbited the next space station, Salyut 3. Western observers immediately noticed some interesting differences from Salyut 1: the crews sent to the station were all military instead of mixed military and civilian, when the crew entered the space station they switched to military telemetry, the orbit was lower (perhaps to improve picture resolution), and after it was unoccupied for a month, a data capsule was separated and returned to Earth in a manner similar to the return of photographic reconnaissance film. Therefore, this is counted in the West as the first military space station, optimized for reconnaissance activities. The Soviets stated that it was for Earth resources investigations. Of the two crews sent to Salyut 3, only one (Soyuz 14) was able to dock with it.

Salyut 4, launched December 26, 1974, was similar to Salyut 1 and so is considered a civilian mission by Western analysts. Two crews docked with it (Soyuz 17 for 30 days and Soyuz 18 for 63 days), although a third (called the April 5th Anomaly or Soyuz 18A) was supposed to dock. In that case, a problem in the launch vehicle resulted in an abort which brought the crew back to Earth (unharmed) before reaching orbit. In November 1975, the automated Soyuz 20 docked with the station for a 90-day powered down test of the Soyuz spacecraft (biological specimens were carried for scientific experiments).

The next station, Salyut 5, was similar to Salyut 3, suggesting the Soviets had an alternating program of military and civilian space stations during this period. Two crews successfully occupied Salyut 5 (Soyuz 21 for 46 days, Soyuz 24 for 18 days), while a third (Soyuz 23) was unable to dock.

Between the first two missions to Salyut 5, the Soviets launched another free-flying mission, Soyuz 22, which tested an East German multispectral camera (the MKF-6) for Earth resources studies. A modified version of the camera was installed on Salyut 6 and 7.

The Second Generation: Salyut 6 and 7

On September 29, 1977, the Soviets launched a second-generation space station called Salyut 6. The most important improvement in the station was the addition of a second docking port at the aft end of the station which enabled resupply flights to dock with the station while a crew was on board. Flights of a new automated cargo ship, called Progress, began in 1978, and the first in-space fuel transfer took place between Progress 1 and Salyut 6 in January of that year. Progress is a modified Soyuz spacecraft and not designed to survive reentry, thus it can take supplies to a space station, but cannot bring anything back to Earth. The second port was also used for docking additional crews to occupy the station as visitors to the long-duration crew. This provided opportunities for taking supplies to the orbiting crew, and for bringing the results of the various experiments conducted on board back to Earth (which would otherwise have to wait until the main crew returned).

During its four and a half years in orbit, Salyut 6 hosted 16 crews (2 others were unable to dock) which conducted a wide variety of Earth resources, materials processing, biomedical, and biological experiments (such as plant growth). The station was occupied for approximately 50 percent of the time it was in orbit.

During the Salyut 6 period, the Soviets increasedþ553[illegible]tion for a crew in space to 185 days (the longest U.S. spaceflight is 84 days). The long duration crews would be visited by other crews who would remain for a week. Among the visiting crews were the first "international cosmonauts" representing the countries that belong to Interkosmos, the organization through which the Soviets cooperate with their allies. Cosmonauts from Cuba, Czechoslovakia, East Germany, Hungary, Mongolia, Poland, Romania, and Vietnam all visited Salyut 6. A Bulgarian was launched, but was not able to dock because the Soyuz 33 ferry craft malfunctioned. (The Soviets launched a Bulgarian in 1988 to the new Mir space station.)

A total of 12 Progress flights resupplied the crews, and three other automated missions (Soyuz 34, Soyuz T, and Cosmos 1267) docked with the station. Soyuz 34 was launched to replace the aging Soyuz 32 for returning the crew to Earth after the Soyuz 33 failure. Soyuz T was an automated test of a new version of Soyuz with upgraded avionics and other changes. The Soyuz T replaced the original Soyuz in 1981 and was used until it was replaced by another modified version, Soyuz TM, in 1986. Cosmos 1267 docked with Salyut 6 in June 1981. The Soviets announced that its purpose was testing a modular space station concept, and that Cosmos 1267 had life support systems on-board. Later, *Aviation Week and Space Technology* reported that Cosmos 1267 was in fact a "battle station" in orbit, armed with infrared homing devices. Salyut 6 and Cosmos 1267 were deorbited on July 29, 1982, while they were still docked. The full nature of Cosmos 1267's mission remains unclear, but probably was a modular space station test as the Soviets claimed.

Salyut 7 was launched on April 19, 1982, the eleventh anniversary of the launch of Salyut 1. The space station is virtually identical to Salyut 6, although the Soviets report that it has an improved navigation system. It was last occupied in 1986, and the Soviets have stated that they do not intend to reactivate Salyut 7 since the new Mir space station is available. Salyut 7 is now in a high orbit (500 kilometers) in a mothballed condition, and the Soviets plan to monitor the station to see how its systems deteriorate over time. According to Soviet sources, all the fuel on Salyut 7/Cosmos 1686 has been depleted and they are now considering options for dealing with its reentry.

Salyut 7 hosted 10 crews and was resupplied by 13 Progress missions. During the Salyut 7 era, a new record of 237 days was set by a three-man crew in 1984. Among the visiting crews to Salyut 7 were a Frenchman, an Indian, and a Soviet woman, Svetlana Savitskaya, who made two flights, the first woman to do so. On the second flight, she also became the first woman to make a spacewalk.

Two modules, Cosmos 1443 and Cosmos 1686, based on the Cosmos 1267 design, were docked with Salyut 7 (Cosmos 1686 is still attached). The Soviets refer to these as multipurpose vehicles that can be used as cargo ships (with 2.5 times the capacity of Progress), space tugs, and/or modules to increase the habitable volume of the space station by 50 cubic meters. Cosmos 1443 also had a descent module for returning material to Earth, although Cosmos 1686 does not.

During the Salyut 7 period, the Soviets had to overcome many difficulties with the space station itself, and nearly suffered another tragedy in 1983 when a launch vehicle about to send a crew into orbit caught fire. Using the emergency abort tower on top of the launch vehicle, the module containing the crew was propelled away from the launch pad and landed safely 3 kilometers away.

The hardware problems with the space station led the Soviets to begin using EVA routinely during the Salyut 7 era. It was only in 1983 that a single crew performed two EVAs on one mission. Their purpose was to attach new solar panels to the main space station arrays to provide additional power and compensate for degradation of the original panels. Subsequent crews added more solar panels, one set of which were made of gallium arsenide, apparently the first time this substance had been used for space solar panels. The 1983 experience gave the Soviets confidence in repeated spacewalks by a single crew, and in 1984 a crew made six EVAs, five of which were needed to replace a fuel valve. The sixth was used to add more solar panels.

In 1985, the space station required another round of major repairs after it lost electrical power during a period that it was unoccupied. The station was essentially in a deep-freeze condition when the Soyuz T-13 repair crew arrived. Communications and radar systems were not functioning, complicating rendezvous and docking operations. The two-man crew reactivated the station and later became part of the first crew transfer. The three-man Soyuz T-14 crew was sent to Salyut 7, and for one week all five men shared the space station. Then, one member of the Soyuz T-13 crew and one from Soyuz T-14 returned to Earth, leaving one member of the Soyuz T-13 crew and two from Soyuz T-14 aboard. Such crew transfers had been expected for years, since they are required for permanently occupied facilities (individuals would not remain on the space station for years at time; instead they would be replaced probably on a three or four month schedule).

The Soyuz T-14 crew also represented another space first; it was the first known space mission aborted because of a medical emergency. The commander of the mission, Vladimir Vasyutin, developed an "inflammation" which could not be cured with medical supplies aboard the space station and the crew had to return in haste. The Soviets have not provided further details about Vasyutin's affliction. The Soyuz T-15 crew, after first spending time on the new Mir space station in 1986 (see below), spent 50 days aboard Salyut 7 closing out activities.

Third Generation: Mir ("Peace")

On February 20, 1986, the Soviets launched a third generation space station called Mir, the Russian word for peace. That the space station carries this name is not surprising since in 1985 the Soviets placed a proposal called "Star Peace" before the United Nations to counter President Reagan's "Star Wars" program. They have continued to open their space program, and created a "civilian" space agency called Glavkosmos (discussed in chapter 6) in 1985 to promote the image of a space program devoted to peaceful purposes. Calling their new space station Mir, rather than Salyut 8, is clearly part of this effort.

Mir is about the same size as the earlier Soviet space stations (they are all launched by the same vehicle), but has some significant differences. It has six docking ports rather than two, and most of the scientific equipment that normally is installed inside the space station will be carried instead on separate modules that will dock at one of the ports, leaving a greater volume of space available in the station itself for the crew. This has enabled, for example, the provision of private sleeping quarters for two crew members. More quarters may be included on the modules sent to dock with Mir. The modification was made in response to complaints by previous crews about the lack of privacy. The Soviets have also made a point of stating that Mir has more and better computers to operate the station, relieving the crew of many routine tasks. Communications between Mir and ground control can be routed through a relay satellite, permitting greater communication times with the crews.

There are two axial docking ports (one at each end), and four ports around the circumference of one end of the station. Modules docking at one of the side ports dock first with the forward axial port and then are swung around using a type of remote manipulator system. The additional ports give the Soviets a more flexible system, permitting them to carry out several different research activities in specialized modules that can be docked with the station part of the time and in free flight (away from human interference) on other occasions.

1986-1987. Only one crew, Soyuz T-15, docked with Mir in 1986; two Progress missions brought supplies. After spending 51 days on Mir, the crew used their Soyuz spacecraft to taxi over to Salyut 7 where they spent another 50 days closing out activities. They also tested a flexible structure, extending it and then collapsing it again. The exercise is related to building large space structures in the future. They then taxied back to Mir and stayed for another 19 days.

A new crew was launched to Mir on February 5, 1987, and one of its two members, Yuriy Romanenko, went on to set a new duration record of 326 days. His companion, Aleksandr Laveikin, had to be replaced in the middle of the mission because of heart irregularities. A pre-scheduled visiting mission (that included a Syrian cosmonaut) was used to substitute Aleksandr Aleksandrov as Romanenko's crewmate. This personnel switch demonstrated the growing ability of the Soviet program to adapt to changing circumstances.

While Romanenko and Laveikin were aboard, they demonstrated one of the benefits of having a crew aboard a space station when they "rescued" the first module sent to Mir, an astronomical observatory called Kvant, which also carries gyroscopes for controlling the space station's orientation. The first attempt to dock Kvant with Mir failed because of a problem with Kvant's docking systems. The second attempt partially succeeded, but a hard docking could not be achieved. The crew performed a spacewalk to investigate the problem and discovered a foreign object in the docking port. They removed it and a hard dock was finally accomplished. The cosmonauts admitted when they returned to Earth that it had been a plastic toilet bag that had fallen into the docking adapter unnoticed when they were throwing trash into a Progress cargo vehicle docked with the station.

The crew also performed two more spacewalks to add a third main solar panel to Mir. Perhaps because of weight considerations, Mir was launched with only two of its three main arrays. Unlike the previous solar panel additions, which involved attaching more solar cells to existing arrays, this time the crew had to install the entire assembly, including connections into the space station.

As Romanenko's record-breaking mission came to an end in December 1987, the Soviets launched a new crew that took over Mir operations. In the 1985 crew transfer, the Soviets had left one of the original crew members on the space station with the new crew, but this time it was a complete crew replacement. At the end of 1987, Mir was occupied by Vladimir Titov and Musa Manarov. During 1987, there were seven Progress resupply missions.

1988-1989. Titov and Manarov were launched on December 21, 1987, with another cosmonaut, Anatoliy Levchenko, whom the Soviets stressed was an experienced test pilot. He returned to earth with Romanenko and Aleksandrov after a week in orbit. His flight was interesting because the Soviets emphasized that it was related to their development of a reusable space shuttle. Immediately after landing, Levchenko was taken to an airfield where he piloted an aircraft, apparently to determine if a week in weightlessness affected his flying skills. (Levchenko died of a brain tumor in August 1988; the Soviets stress that his death was unrelated to his spaceflight.)

Titov and Manarov remained on Mir until December 21, 1988, for a new record of 366 days. During the year, they were visited by three crews, each composed of two Soviets and one international cosmonaut. The countries represented on Soviet crews were Bulgaria in June, Afghanistan in August and France in November.

On the June flight, all three cosmonauts returned to Earth after a week in space, but one of the Soviet cosmonauts on the August flight, Polyakov, remained aboard Mir while his Soviet and Afghani colleagues returned. A physician, he monitored the health of Titov and Manarov during the end of their record-breaking flight, and remained on the space station after they left with two new crew-members who arrived in November. The two new space station occupants, Volkov and Krikalev, came with the Frenchman, Chretien, who stayed for three weeks, the longest space journey for any international cosmonaut. Chretien also was the first non-Soviet, non-American to make a spacewalk, and returned to Earth with Titov and Manarov in December.

The year was not trouble-free. A spacewalk in June to repair the Kvant astrophysical telescope was unsuccessful when the tool the cosmonauts were using broke; a second excursion was required four months later. On September 6, the Soviet/Afghani crew was returning to Earth when computer problems, exacerbated by pilot error, left them stranded in orbit for a day, after which they landed safely. When the next crew returned (Titov, Manarov and Chretien), they also encountered computer problems which delayed landing for three hours.

At the end of 1988, the three cosmonauts on Mir were Volkov, Krikalev, and Polyakov. The Soviets announced that they would be replaced by a new crew in April, as the permanent occupancy of Mir continued. In April, however, the Soviets changed their mind and decided not to launch a new crew primarily because two modules intended to dock with Mir still were not ready. One is a special airlock to make it easier for the cosmonauts to leave the space station for spacewalks, and the other is equipped for materials processing research. Without the modules, there would have been little for the crew to do. Mir was vacant from April until September, when a new crew (Viktorenko and Serebrov) was launched with the expectation that the airlock module would soon follow. There were additional technical delays with the module, however, and it was not launched until November. Designated Kvant 2, it docked with Mir in early December. In January and February 1990, Viktorenko and Serebrov made five spacewalks, two of which tested a self-contained backpack similar to the U.S. "Manned Maneuvering Unit" flown on the space shuttle, to enable crews more freedom in operating in space (the backpacks contain all life support systems so the crew member does not have to be attached by an umbilical to a spacecraft like the shuttle or Mir, as well as propulsion to maneuver near the spacecraft). Viktorenko and Serebrov were replaced by a new crew (A. Solovyev and Balandin) in February, 1990 and the materials processing module is expected to be launched in the spring.

On all of their space stations, the Soviets have conducted a wide range of experiments in remote sensing, materials processing, and biology, as well as astronomical and atmospheric studies. They are detailed in the series of reports CRS prepares for the Senate (see Introduction).

U.S. Space Stations

Skylab

On May 14, 1973, the United States orbited a space station developed from a Saturn IV-B stage called Skylab. The space station suffered considerable damage when its micrometeoroid shield and one of the main solar panels were ripped off during launch, but the first crew to visit the station effected repairs, and ultimately three crews docked with Skylab, for 28, 59, and 84 days respectively. A wide range of experiments were conducted in solar observations, Earth resources observations, biomedical research, and materials processing. The last crew left the space station in February 1974, and in July 1979 the station reentered the Earth's atmosphere, raining debris over parts of Western Australia and the Indian Ocean.

The U.S./International Space Station "Freedom"

In his January 1984 State of the Union address, President Reagan called on NASA to build a permanently occupied space station within a decade. NASA is now embarked on a program with the European Space Agency, Japan and Canada to build such a station, but NASA estimates that it will not be available until at least 1996 instead of 1994.

The space station, named *Freedom* in 1988, has gone through several design reviews. Originally, it was to have consisted of three different objects: an occupied base where astronauts would live and work; an automated platform nearby (a "co-orbiting" platform) for experiments that would be adversely affected by the presence of humans; and an automated platform circling the Earth's poles (a "polar" platform) for observations of the entire globe (the occupied base and co-orbiting platform would be in orbits that would not allow them to view the entire globe). NASA expected that there would be commonality in some of the systems (such as electrical power and communications) on the occupied base and two platforms. In 1987, NASA announced that the space station would be built in two phases: Phase 1 would include the polar platform and the occupied base, but with less of the lattice-work structure for the base that would be used for scientific experiments and other operations; and Phase 2, which would include the co-orbiting platform and the rest of the lattice-work structure. Phase 2 since has been indefinitely postponed. In 1989, NASA divorced the polar platform from the space station program because it became clear that there would be little if any technical commonality between the platform and the occupied base. NASA's Office of Space Science and Applications has taken over the polar platform, since its use is primarily for environmental observations (see section on Mission to Planet Earth in Chapter 3).

Today, then, the space station is only the occupied base. According to current plans, it will consist of one module for crew quarters (provided by the United States) and three laboratory modules, one each provided by the United States, the European Space Agency and Japan. The modules will be attached to a lattice-work truss structure, which will also accommodate solar panels (to provide electrical power) and other space station systems. Canada is building a Mobile Servicing System, and the United States is building a Flight Telerobotic Servicer, to facilitate work in the vicinity of the space station (such as servicing space station systems). NASA's current schedule calls for "first element launch" at the end of 1995, initial occupancy in 1996, permanent occupancy in 1997, and construction complete in 1999, a delay of two years over the schedule as it existed in the summer of 1989.

The cost for research and development for the space station is estimated at $19 billion through 1996 (real year dollars assuming 5 percent inflation). Total program costs are estimated at $30 billion if factors such as transportation and ground facilities are included. In addition, the international partners will contribute $7 billion to the program. These high costs, and continued debate over the purpose of and need for the space station, have made this program extremely controversial, and the issues cannot be discussed here in sufficient depth (see CRS Issue Brief 85209, *Space Stations*, for more information).

Future Space Stations

While there is considerable discussion in the media and among aerospace professionals about the potential for space colonies, there are no firm plans for such an endeavor at this time. A popular scenario calls for construction of a 10,000 person colony at a Lagrange point where the gravitational forces of the Earth and Moon cancel each other out. This is often called the L-5 proposal, denoting one of the five Lagrange coordinates in the Earth-Moon system.

Broader proposals for future space stations were made in the 1986 report of the National Commission on Space (see chapter 7). The Commission recommended creation of a space infrastructure to support opening the inner solar system for science, exploration, and development over the next 50 years. In doing so, space stations (or spaceports as the Commission calls them) would be established in Earth, Moon and Mars orbits, and at the L1 Lagrange point. In addition, the Commission's "cycling spaceships" for transportation to Mars would be similar in design to the spaceports. All would have the ability to produce artificial gravity to compensate for the deleterious effects of weightlessness on the human body over long periods of time. The spaceports would be transfer points in the transportation system rather than colonies; the Commission felt that space colonies such as those proposed by the L5 supporters were beyond the 50 year time frame of its report.

Long-term Soviet space station plans are not known with any certainty. A 1983 Pravda article discussed a complex of installations at altitudes ranging from 200 to 4,000 kilometers linked to Earth by freight and passenger transport spacecraft. The current debate in the Soviet Union over the wisdom of space spending (see Introduction) may slow plans for expansive utilization of Earth orbit, however. The Soviets have mentioned development plans for "Mir-2," but no date has been given for when it might be launched. Since the existing Mir space station still is not fully utilized (only two of the five planned modules have been launched), there is no overwhelming need for a replacement station yet.

REUSABLE SPACE VEHICLES

The U.S. Space Shuttle

In 1972, President Nixon approved development of a reusable piloted spacecraft, called the space shuttle. The shuttle consists of a reusable orbiter about the size of a DC-9 which carries the crew and payloads, the external tank which holds the fuel for the three liquid hydrogen-liquid oxygen engines (called the main engines) for the orbiter, and two solid rocket boosters (SRBs) attached to either side to provide additional power during the first two and a half minutes of launch. The external tank breaks up in pieces as it reenters over the Indian Ocean; the SRBs are recovered from the Atlantic Ocean for refurbishment and reuse. Four flight-worthy orbiters were built: *Colombia*, *Challenger*, *Discovery*, and *Atlantis*. A fifth orbiter, *Enterprise*, was used for tests in the late 1970s, but was not designed to be flown in space. It is now on display by the Smithsonian Institution near Dulles Airport in Virginia. As discussed below, *Challenger* was destroyed in 1986. A replacement orbiter, *Endeavour*, is under construction.

The Challenger Tragedy

After making 24 successful flights, the shuttle program suffered a tremendous tragedy when the 25th mission, STS 51-L, exploded 73 seconds after liftoff on January 28, 1986, at Cape Canaveral, Florida. The orbiter *Challenger* was destroyed and all seven crew members were killed--NASA astronauts Francis "Dick" Scobee, Michael Smith, Judith Resnik, Ronald McNair, and Ellison Onizuka and payload specialists Gregory Jarvis (an engineer with Hughes Aircraft Inc.) and S. Christa McAuliffe (a schoolteacher). The failure of a joint in one of the SRBs was blamed for the accident.

The investigation of the *Challenger* tragedy was performed by a commission established by President Reagan, called the Rogers Commission after its chairman, former Secretary of State William Rogers. Although the Commission did not affix blame to any individuals, the public record made clear that employees at NASA and Morton Thiokol, which manufactures the SRBs, should have chosen not to launch that day. The weather was unusually cold at Cape Canaveral and temperatures had dipped below freezing during the night. Test data had suggested that the seals (called O rings) around the SRB joints lost much of their effectiveness in very cold weather. A Thiokol engineer at the launch site had recommended against launch, but was overruled by his superiors at the company's Utah headquarters. NASA's Marshall Space Flight Center was responsible for the SRB program within the agency, and officials there approved the launch as well.

Pre-Challenger Shuttle Missions

The aftermath of the *Challenger* tragedy called into question NASA management practices, past decisions about the design of the SRBs, and the health of the U.S. civilian space program. To a large extent, the tragedy overshadowed the successes that the shuttle program enjoyed prior to January 28, 1986.

The first space shuttle flight was successfully accomplished on April 12, 1981, and was followed by three more orbital test flights (one in 1981, two in 1982). The first "operational" launch of the shuttle took place on November 11, 1982, and was used to send two communications satellites into geostationary orbit.

Four shuttle missions were launched in 1983, including missions that included the first U.S. woman in space (Sally Ride) and the first black American (Guion Bluford), and the first flight of the European-built Spacelab, which flies in the cargo bay of the orbiter. The Spacelab 1 mission included the first non-American to fly on an American piloted mission (a West German). Five shuttle missions were successfully accomplished in 1984, and included the first use of the Manned Maneuvering Unit which allows an astronaut to travel away from the shuttle without being tethered to it. On later flights that year, three satellites were retrieved by astronauts, one of which (the Solar Maximum Mission) was repaired and redeployed in orbit, while the other two (Westar and Palapa) were returned to Earth for repair and eventual relaunch. Kathryn Sullivan became the first American woman to perform a spacewalk, Sally Ride became the first American woman to fly into space twice, and procedures for in-space refueling were demonstrated.

In 1985, nine shuttle flights were successfully accomplished, including the first dedicated mission for DOD. This mission garnered considerable attention from the media, which was unaccustomed to the lack of information about launch schedules and payloads involved in a DOD launch. The media portrayed this an example of the "militarization" of NASA, but it may be viewed as a continuation of past policy as all U.S. launch vehicles are used by both military and civilian customers.

During 1985, shuttle crew size increased to eight, and one of the crews included U.S. Senator Jake Garn. The utility of the shuttle for repairing satellites was demonstrated again with the repair of the Leasat communications satellites which had failed to function after deployment on an earlier shuttle flight. Two Spacelab missions were flown, including one with animals, the first time humans and animals have flown together in space. Another crew tested space construction techniques. One of the 1985 missions encountered the first serious problem during launch when one of the three main engines ceased functioning during ascent. The crew safely reached orbit, although it was not at the altitude intended.

There was one successful shuttle launch in January 1986 which included U.S. Congressman Bill Nelson among the crew. The next flight was the ill-fated STS 51-L.

Return to Flight

On September 29, 1988, the space shuttle made its first flight since the *Challenger* disaster. The mission, using the orbiter *Discovery*, deployed a Tracking and Data Relay Satellite identical to the one lost aboard *Challenger*. The five crew members--Frederick (Rick) Hauck, Richard Covey, John (Mike) Lounge, David Hilmers, and George (Pinky) Nelson--remained in orbit for four days. A second shuttle flight, dedicated to DOD requirements, was launched in December.

During 1989, NASA conducted five shuttle launches, slowly increasing the flight rate to a planned 12-14 missions per year. The five missions all carried spacecraft into orbit: the Magellan mission to Venus, and the Galileo mission to Jupiter (both discussed in Chapter 4); another Tracking and Data Relay Satellite; and two Department of Defense satellites. In the future, the shuttle will be used less as "truck" carrying satellites to orbit, and more as a laboratory and earth observation platform. Activities that do not require the presence of a crew or the unique capabilities of the shuttle, such as routine satellite launches, will use "expendable launch vehicles" or ELVs (rockets).

Aerospace Plane

For the longer term future, the United States is conducting research and development on several new propulsion technologies and materials through the National Aero-Space Plane (NASP) program. The concept is not new, but it is believed that the technologies are finally becoming available to achieve a marriage between air-breathing and rocket engine technologies. Ultimately, NASP could lead to a replacement for the space shuttle and other launch vehicles for taking people and some cargo into orbit. It could also lead to the development of a commercial aircraft capable of taking people around the world in a few hours. It is in this application that President Reagan referred to it as the "Orient Express" in his 1986 State of the Union address.

The NASP program is funded through the Air Force and NASA. The near-term goal of the program is to develop an "X" plane (in the mold of the X-1 or X-15) to test whatever materials and technologies have been developed through the research program at that time. Aerospace plane technologies are so advanced that it is not known yet whether or not they will lead to operational vehicles, much less what they will cost. The NASP program was very controversial in 1989, and led to a National Space Council review of the program. The Space Council recommended that the program be slipped by two and a half years, and that it continue to be funded jointly by DOD and NASA (DOD had wanted to terminate its involvement). NASP is discussed in more detail in CRS Issue Brief 89128, *National Aero-Space Plane*.

Soviet Space Shuttle

After years of Western speculation, the Soviets finally admitted in 1987 that they were, in fact, developing a space shuttle of their own. On November 15, 1988, the first flight of the Soviet shuttle took place in a completely automated mode--no crew was aboard. The shuttle, called Buran, made two orbits of the Earth and then landed on a runway 12 kilometers from the pad from where it had been launched. The launch took place two weeks after an earlier attempt was terminated 51 seconds before liftoff when a computer determined that a launch service tower had not retracted sufficiently.

The Soviet shuttle physically resembles the U.S. shuttle, prompting some Western observers to charge that it is a "carbon copy" of the American version. This is an exaggeration, however. The Soviet shuttle is different in concept from the U.S. shuttle. Each time the U.S. shuttle is launched, all four pieces (the airplane-like orbiter, the two side-mounted Solid Rocket Boosters, and the large cylindrical External Tank) must be used. The main engines for achieving orbit are on the orbiter; the External Tank simply holds the fuel for them. Thus, whatever is being carried into space is limited to a size and weight that can fit inside the orbiter's cargo bay. The Soviets built a more versatile system in that the main engines are on the Energiya launch vehicle (see chapter 6) itself. The orbiter exists independently so that if they have something too large or too heavy to fit inside their orbiter's cargo bay, they can simply leave the orbiter off and the cargo can be attached directly to Energiya. Thus the Soviets have a launch vehicle (Energiya) that can be used to place anything in space up to 100 tons in mass--the orbiter is only one payload it can carry.

Initial Western reports that the Soviet shuttle is equipped with air-breathing engines to provide an ability to attempt a second landing if necessary proved inaccurate. The Soviets have stated that their shuttle must land on the first attempt (like its U.S. counterpart), and that they are building two contingency landing sites, one in the Western Soviet Union and one in the eastern part of the country. For now, the landing strip at Tyuratam is apparently the only one.

During 1989, the Soviets consistently stated that the next flight of Buran would take place in 1991 and would not carry a crew. The first flight with a crew is planned for 1992. (In 1988, they had said there would be another flight in 1989.) After the test phase, the Soviets stated that they would launch their shuttle only once a year. There are conflicting statements on how many shuttles will be built (there are two flightworthy shuttles today), but all apparently will be named Buran (unlike the U.S. program where each orbiter has its own name). Where Buran fits into the overall Soviet space program continues to be unclear, both in the West and apparently in the Soviet Union as well. Soviet space officials have offered lists of missions for Buran to accomplish, but all seem far in the future (construction of solar power stations, for example). The delay in the next Buran flight may be partially attributable to technical difficulties, but probably is more related to lack of support for the program at a time of increased budget constraints in the Soviet space program. In 1989, the Soviets stated that the Energiya/Buran program consumed $2 billion of their $11 billion/year space budget.

In addition to the shuttle, Western sources have stated that the Soviets are developing a smaller "spaceplane." From 1982-1984, four orbital tests were made of what the U.S. Department of Defense (DOD) said was a sub-scale prototype; DOD stated that a dozen tests took place through 1989 (the others presumably were suborbital). All four orbital tests were launched from the Kapustin Yar launch facility, and all landed in the water (the first two in the Indian Ocean, the last two in the Black Sea). Each made one and a quarter orbits of the Earth. The four spacecraft and their launch dates are: Cosmos 1374, June 3, 1982; Cosmos 1445, March 15, 1983; Cosmos 1517, December 27, 1983; and Cosmos 1614, December 19, 1984. In 1989, Soviet space officials stated categorically that these flights were related to the development of the Buran space shuttle, not a separate spaceplane program.

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1961						
Apr. 12	Vostok 1	Gagarin	4725	1:48	same	1:48
May 5	MR-3	A. Shepard	1290	:15	same	:15
July 21	MR-4	Grissom	1286	:16	same	:31
Aug. 6	Vostok 2	G. Titov	4731	25:18	same	27:06
1962						
Feb. 20	MA-6	Glenn	1355	4:55	same	5:26
May 24	MA-7	Carpenter	1349	4:56	same	10:22
Aug. 11	Vostok 3	Nikolayev	4722	94:22	same	121:28
Aug. 12	Vostok 4	Popovich	4728	70:57	same	192:25
Oct. 3	MA-8	Schirra	1373	9:13	same	19:35
1963						
May 15	MA-9	Cooper	1376	34:20	same	53:55
June 14	Vostok 5	Bykovskiy	4720	119:06	same	311:31
June 16	Vostok 6	Tereshkova	4713	70:50	same	382:21
1964						
Oct. 12	Voskhod 1	Komarov Yegorov Feoktistov	5320	24:17	same	455:12
1965						
Mar. 18	Voskhod 2	Bel'yayev Leonov	5682	26:02	same	507:16
Mar. 23	Gemini 3	Grissom (2) Young	3225	4:53	same	63:41
June 3	Gemini 4	McDivitt White	3574	97:56	same	259:33
Aug. 21	Gemini 5	Cooper (2) Conrad	3605	190:55	same	641:23
Dec. 4	Gemini 7	Borman Lovell	3663	330:35	same	1302:33
Dec. 15	Gemini 6	Schirra (2) Stafford	3546	25:51	same	1354:15
1966						
Mar. 16	Gemini 8	Armstrong Scott	3788	10:41	same	1375:37
June 3	Gemini 9	Stafford (2) Cernan	3750	72:21	same	1520:19
July 18	Gemini 10	Young (2) Collins	3741	70:47	same	1661:53
Sept. 12	Gemini 11	Conrad (2) Gordon	3860	71:17	same	1804:27
Nov. 11	Gemini 12	Lovell (2) Aldrin	3763	94:35	same	1993:37

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE		VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1967							
Jan.	27	AS-204	Grissom (3)+ White (2)+ Chaffee+	20412	[Not a space flight, but date of fatal fire on pad during pre-flight test.]		
Apr.	23	Soyuz 1	Komarov (2)+	6450	26:48	same	534:04
1968							
Oct.	11	Apollo 7	Schirra (3) Eisele Cunningham	20509	260:09	same	2774:04
Oct.	26	Soyuz 3	Beregovoy	6575	94:51	same	628:55
Dec.	21	Apollo 8	Borman (2) Lovell (3) Anders	43663	147:01	same	3215:07
1969							
Jan.	14	Soyuz 4*	Shatalov Yeliseyev Khrunov	6625	71:21	71:21 47:49 47:49	795:54
Jan.	15	Soyuz 5*	Volynov	6585	72:54	72:54	868:48
Mar.	3	Apollo 9	McDivitt (2) Scott (2) Schweickart	43185	241:01	same	3938:10
May	18	Apollo 10	Stafford (3) Young (3) Cernan (2)	48638	192:03	same	4514:19
July	16	Apollo 11	Armstrong (2) Collins (2) Aldrin (2)	49698	195:19	same	5100:16
Oct.	11	Soyuz 6	Shonin Kubasov	6577	118:43	same	1106:14
Oct.	12	Soyuz 7	Filipchenko Gorbatko V. Volkov	6570	118:40	same	1462:14
Oct.	13	Soyuz 8	Shatalov (2) Yeliseyev (2)	6646	118:51	same	1699:56
Nov.	14	Apollo 12	Conrad (3) Gordon (2) Bean	49804	244:36	same	5834:04
1970							
Apr.	11	Apollo 13	Lovell (4) Haise Swigert	49990	142:55	same	6262:49
June	1	Soyuz 9	Nikolayev (2) Sevast'yanov	6500	424:59	same	2549:54

CRS-26

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1971						
Jan. 31	Apollo 14	A. Shepard (2) Roosa Mitchell	46347	216:02	same	6910:55
Apr. 19	Salyut 1	(Occupied by Soyuz 11 crew)	18600			
Apr. 22	Soyuz 10	Shatalov (3) Yeliseyev (3) Rukavishnikov	6575	47:46	same	2693:12
June 6	Soyuz 11	Dobrovolskiy+ V. Volkov (2)+ Patsayev+	6575	570:22	same	4404:18
July 26	Apollo 15	Scott (3) Irwin Worden	52759	295:12	same	7796:31
1972						
Apr. 16	Apollo 16	Young (4) Mattingly Duke	51571	265:51	same	8594:04
Dec. 7	Apollo 17	Cernan (3) Schmitt Evans	51808	301:52	same	9499:40
1973						
May 14	Skylab 1	(Occupied by Skylab 2, 3 & 4 crews)	89439			
May 25	Skylab 2	Conrad (4) Kerwin Weitz	30803	672:50	same	11518:10
July 28	Skylab 3	Bean (2) Garriott Lousma	30694	1427:09	same	15799:37
Sept. 27	Soyuz 12	Lazarev Makarov	6575	47:16	same	4498:50
Nov. 16	Skylab 4	Carr E. Gibson Pogue	31232	2017:16	same	21851:25
Dec. 18	Soyuz 13	Klimuk Lebedev	6575	188:56	same	4876:42
1974						
June 24	Salyut 3	(Occupied by Soyuz 14 crew)	18900			
July 3	Soyuz 14	Popovich (2) Artyukhin	6570	377:30	same	5631:42
Aug. 26	Soyuz 15	Sarafanov Demin	6570	48:12	same	5728:06

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE		VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1974 (cont.)							
Dec.	2	Soyuz 16	Filipchenko (2) Rukavishnikov (2)	6570	142:24	same	6012:54
Dec.	26	Salyut 4	(Occupied by Soyuz 17, 18 crews)	18900			
1975							
Jan.	10	Soyuz 17	Gubarev Grechko	6570	709:20	same	7431:34
Apr.	5	Anomaly (Soyuz 18A)	Lazarev (2) Makarov (2)	6570	:20	same	7432:14
May	24	Soyuz 18	Klimuk (2) Sevast'yanov (2)	6570	1511:20	same	10454:54
July	15	Soyuz 19	Leonov (2) Kubasov (2)	6800	142:31	same	10739:56
July	15	ASTP	Stafford (4) Slayton Brand	14743	217:28	same	22503:49
1976							
June	22	Salyut 5	(Occupied by Soyuz 21, 24 crews)	18900			
July	6	Soyuz 21	Volynov (2) Zholobov	6570	1182:23	same	13104:42
Sept.	15	Soyuz 22	Bykovskiy (2) Aksenov	6570	189:52	same	13484:26
Oct.	14	Soyuz 23	Zudov Rozhdestvenskiy	6570	48:07	same	13580:40
1977							
Feb.	7	Soyuz 24	Gorbatko (2) Glazkov	6570	425:26	same	14431:32
Sept.	29	Salyut 6	(Occupied by Soyuz 26, 27, 28, 29, 30, 31 32, 35, 36, 37, 38, T2, T3, T4, 39, 40 crews)	18900			
Oct.	9	Soyuz 25	Kovalenok Ryumin	6570	48:45	same	14592:02
Dec.	10	Soyuz 26	Romanenko Grechko (2)	6570	898:06	2314:00	19157:02
1978							
Jan.	10	Soyuz 27	Dzhanibekov Makarov (3)	6570	1558:53	142:59	19443:00
Mar.	2	Soyuz 28	Gubarev (2) Remek (Czechoslovakia)	6570	190:16	same	19823:32
June	15	Soyuz 29	Kovalenok (2) Ivanchenkov	6570	1911:23	3350:48	26525:08

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1978 (cont.)						
June 27	Soyuz 30	Klimuk (3) Hermaszewski (Poland)	6570	190:03	same	26905:14
Aug 26	Soyuz 31	Bykovskiy (3) Jahn (German Dem. Rep.)	6570	1628:14	188:49	27282:52
1979						
Feb. 25	Soyuz 32	Lyakhov Ryumin (2) (Returned unoccupied)	6570	2596:24	4200:36	35684:04
Apr. 10	Soyuz 33	Rukavishnikov (3) Ivanov (Bulgaria)	6570	47:01	same	35778:06
June 6	Soyuz 34	(Launched unoccupied, returned Soyuz 32 crew)	6570	1770:17		
1980						
Apr. 9	Soyuz 35	Popov Ryumin (3)	6570	1321:29	4436:12	44650:30
May 26	Soyuz 36	Kubasov (3) Farkas (Hungary)	6570	1580:54	188:46	45028:02
June 5	Soyuz T-2	Malyshev Aksenov (2)	7000	94:19	same	45216:40
July 23	Soyuz 37	Gorbatko (3) Pham Tuan (Vietnam)	6570	1911:17	188:42	45594:04
Sept. 18	Soyuz 38	Romanenko (2) Tamayo Mendez (Cuba)	6570	188:43	same	45971:30
Nov. 27	Soyuz T-3	Kizim Makarov (4) Strekalov	7000	307:08	same	46892:54
1981						
Mar. 12	Soyuz T-4	Kovalenok (3) Savinykh	7000	1794:38	same	50482:10
Mar. 22	Soyuz 39	Dzhanibekov (2) Gurragcha (Mongolia)	6570	188:43	same	50859:36
Apr. 12	STS 1	Young (5) Crippen	98658	54:21	same	22612:31
May 14	Soyuz 40	Popov (2) Prunariu (Romania)	6570	188:41	same	51236:58

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1981 (cont.)						
Nov 12	STS-2	Engle Truly	103811	54 13	same	22720 57
1982						
Mar 22	STS-3	Lousma (2) Fullerton	106000	192 06	same	23106 07
Apr 19	Salyut 7	(Occupied by Soyuz T-5, T-6, T-7, T-9, T-10, T-11, T-12, T-13, T-14 and T-15 crews)	18900			
May 13	Soyuz T-5	Berezovoy Lebedev (2)	7000	2549 06	5073 05	61383 08
June 24	Soyuz T-6	Dzhanibekov (3) Ivanchenkov (2) Chretien (France)	7000	189 51	same	61962 41
June 27	STS-4	Mattingly (2) Hartsfield	108797	169 11	same	23443 29
Aug 19	Soyuz T-7	Popov (3) Serebrov Savitskaya	7000	2712 51	189 52	62522 17
Nov 11	STS-5	Brand (2) Overmyer J. Allen Lenoir	111201	122 14	same	23932 25
1983						
Apr 4	STS-6	Weitz (2) Bobko Musgrave Peterson	114201	120 24	same	24414 01
Apr 20	Soyuz T-8	V. Titov Strekalov (2) Serebrov (2)	7000	48 18	same	62667 11
June 18	STS-7	Crippen (2) Hauck Ride Fabian Thagard	110013	146 24	same	25146 01
June 27	Soyuz T-9	Lyakhov (2) A. Aleksandrov	7000	3585 46	same	69838 45
Aug 30	STS-8	Truly (2) Brandenstein Thornton Bluford D. Gardner	104675	145 09	same	25871 46

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE		VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1983 (cont.)							
Sept.	26	(Soyuz T-10A)	V. Titov Strekalov	(Not a spaceflight. Crew jettisoned using emergency abort system after fire erupted in launch vehicle prior to launch)			
Nov.	28	STS-9	Young (6) Shaw Parker Garriott (2) Lichtenberg Merbold (W. Germany)	110031	247:47	same	27358:28
1984							
Feb.	3	STS 41-B	Brand (3) R. Gibson McCandless McNair Stewart	113508	191:16	same	28314:48
Feb.	8	Soyuz T-10	Kizim (2) V. Solovyev Atkov	7000	1510:43	5686:50	86899:13
Apr.	3	Soyuz T-11	Malyshev (2) Strekalov (3) Sharma (India)	7000	4365:48	189:41	87468:16
Apr.	6	STS 41-C	Crippen (3) Scobee Hart van Hoften G. Nelson	115342	167:40	same	29153:08
July	17	Soyuz T-12	Dzhanibekov (4) Savitskaya (2) Volk	7000	283:14	same	88317:58
Aug.	30	STS 41-D	Hartsfield (2) Coats Resnik Hawley Mullane C. Walker	119491	144:57	same	30022:50
Oct.	5	STS 41-G	Crippen (4) McBride Ride (2) Sullivan Leestma Scully-Power Garneau (Canada)	110119	197:24	same	31404:38

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1984 (cont.)						
Nov 8	STS 51-A	Hauck (2) D. Walker J. Allen (2) A. Fisher D. Gardner (2)	119421	191:45	same	32363:23
1985						
Jan 24	STS 51-C	Mattingly (3) Shriver Onizuka Buchli Payton	N/A	73:33	same	32731:08
Apr 12	STS 51-D	Bobko (2) D. Williams Hoffman Griggs Seddon C. Walker (2) Garn	113802	167:55	same	33906:33
Apr 29	STS 51-B	Overmyer (2) Gregory Thornton (2) Thagard (2) Lind van den Berg Wang	111982	168:09	same	35083:36
June 6	Soyuz T-13	Dzhanibekov (5) Savinykh (2)	7000	2691:12	2691:12 4035:51	95045:01
June 17	STS 51-G	Brandenstein (2) Creighton Lucid Nagel Fabian (2) Baudry (France) Sultan Salman Al-Saud (S. Arabia)	116310	169:39	same	36271:09
July 29	STS 51-F	Fullerton (2) Bridges Henize England Musgrave Bartoe Acton	114590	190:45	same	37606:24
Aug 27	STS 51-I	Engle (2) Covey Lounge W. Fisher van Hoften (2)	118981	170:18	same	38457:54

TABLE 3a
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE	VEHICLE NAME	CREW (NO. OF FLIGHTS	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1985 (cont.)						
Sept. 17	Soyuz T-14	Vasyutin Grechko (3) A. Volkov	7000	1557:52	1557:52 213:13 1557:52	98373:58
Oct. 3	STS 51-J	Bobko (3) Grabe Hilmers Stewart (2) Pailes	N/A	97:47	same	38946:49
Oct. 30	STS 61-A	Hartsfield (3) Nagel Buchli (2) Bluford (2) Dunbar Ockels (ESA) Furrer (FRG) Messerschmid (FRG)	110568	168:44	same	40296:41
Nov. 26	STS 61-B	Shaw (2) O'Connor Spring Cleave Ross C. Walker (3) Neri (Mexico)	118664	165:05	same	41452:16
1986						
Jan. 12	STS 61-C	R. Gibson (2) Bolden Hawley (2) G. Nelson (2) Chang-Diaz Cenker B. Nelson	116120	146:04	same	42474:44
Jan. 28	STS 51-L	Scobee (2)+ Smith+ Resnik (2)+ Onizuka (2)+ McNair+ Jarvis+ McAuliffe+	121939	Exploded 73 seconds after liftoff. All aboard were killed.		
Feb. 20	Mir	(Occupied by Soyuz T-15, TM2, TM3, TM4, TM5, TM6, TM7 and TM8 crews)				
Mar. 13	Soyuz T-15	Kizim (3) V. Solovyev (2)	7000	3000:01	same	104374:00

TABLE 3e
SUMMARY LIST OF PILOTED SPACE FLIGHTS (Cont.)

LAUNCH DATE		VEHICLE NAME	CREW (NO. OF FLIGHTS)	WEIGHT (KGS)	SHIP DURATION (HR:MIN)	CREW DURATION (HR:MIN)	NATIONAL CUMULATIVE PERSON-HOURS
1987							
Feb.	5	Soyuz TM-2	Romanenko (3) Laveikin	7070	4179:26	7835:38 4179:26	116389:04
July	22	Soyuz TM-3	Viktorenko A. Aleksandrov (2) Faris (Syria)	7070	3847:17	191:05 3847:17 191:05	120618:31
Dec.	21	Soyuz TM-4	V. Titov (2) Manarov Levchenko	7070	4320:55	8782:39 8782:39 189:58	138373:47
1988							
June	7	Soyuz TM-5	Savinykh (3) A. Solovyev A. Aleksandrov (Bulgaria)	7070	2193:47	236:10	139082:17
Aug.	29	Soyuz TM-6	Lyakhov (3) Polyakov Mohmand (Afghanistan)	7070	2741:34	212:27 5782:36 212:27	145289:47
Sept.	29	STS-26	Hauck (3) Covey (2) Lounge (2) Hilmers (2) G. Nelson (2)	102325	97:00	same	42959:44
Nov.	26	Soyuz TM-7	A. Volkov (2) Krikalev Chretien (2) (France)	7070	3635:09	3635:09 3635:09 594:07	153154:12
Dec.	2	STS-27	R. Gibson (3) G. Gardner Mullane (2) Ross (2) W. Shepard	N/A	105:06	same	43485:14
1989							
Mar.	13	STS-29	Coats (2) Blaha Buchli (3) Springer Bagian	83874	119:39	same	44083:29
May	4	STS-30	D. Walker (2) Grabe (2) Thagard (3) Cleave (2) Lee	101119	96:57	same	44568:14
Aug.	8	STS-28	Shaw (3) Richards Leestma (2) Adamson M. Brown	N/A	121:01	same	45173:19
Sept.	5	Soyuz TM-8**	Viktorenko (2) Serebrov (3)	7070	3990:58	same	161136:08
Oct.	18	STS-34	D. Williams (2) McCulley Lucid (2) Baker Chang-Diaz (2)	107092	119:39	same	45771:34
1989 (cont.)							
Nov.	22	STS-33	Gregory (2) Blaha (2) Carter Musgrave (3) K. Thornton	N/A	120:08	same	46372:14

*** Soyuz 4 was launched carrying only Shatalov. Soyuz 5 carried Volynov, Yeliseyev and Khrunov. The latter two transferred to Soyuz 4 via a spacewalk and returned to Earth with Shatalov.**

****Includes all time through the end of the mission on Feb. 19, 1990.**

Prepared by CRS.

+ Fatality. Four Soviets died in spaceflights: Komarov on Soyuz 1 (1967) when the parachute lines tangled during descent; and the Soyuz 11 crew (1971) when an improperly closed vent allowed the cabin atmosphere to vent into space and the three men (who were not wearing spacesuits) asphyxiated. Seven Americans died in the 1986 space shuttle Challenger tragedy when it exploded 73 seconds after launch; three astronauts died in the 1967 Apollo 204 fire.

TABLE 3b. Number of Individuals Who Have Flown in Space

COUNTRY	TOTAL INDIVIDUALS WHO HAVE FLOWN IN SPACE
United States	133
Soviet Union	67
Afghanistan*	1
Bulgaria*	2
Canada+	1
Czechoslovakia*	1
Cuba*	1
France*+	2
German Democratic Republic*	1
Germany, Federal Republic of+	3
Hungary*	1
India*	1
Mexico+	1
Mongolia*	1
Netherlands+	1
Poland*	1
Romania*	1
Saudi Arabia+	1
Syria*	1
Vietnam*	1
TOTAL	222

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*Flew on Soviet spaceflight.
+Flew on U.S. spaceflight.
Prepared by CRS.

CHAPTER 3

SPACE APPLICATION FLIGHTS

Applications satellites are those spacecraft whose functions provide direct applications to a user community, including communications, navigation, remote sensing of the Earth's surface, weather, and geodesy. While the term is usually applied to civilian satellites, they are close cousins of military satellites, and in most cases it is extremely difficult to distinguish whether a particular satellite should be counted as military or civilian. Military space activities in general are discussed in chapter 5.

COMMUNICATIONS

The United States was the first country to experiment with communications satellites. At first, satellites which could store information for later relay to Earth (sometimes referred to as store/dump) were used and, at about the same time, passive balloon reflectors (Echo, for example). Beginning in 1963, the United States started placing communications satellites in geostationary orbit at 35,880 kilometers altitude above the Equator (a satellite in this orbit will maintain a fixed position relative to a given point on the ground). This type of communications satellite receives signals transmitted from a ground station, boosts the power of the signals and instantly retransmits them to another ground station (or sometimes multiple ground stations) hundreds or thousands of kilometers away. Only three properly positioned geostationary satellites are needed to provide global communication.

Communications satellites are used today to send television signals, telephone calls and data around the world. Costs for using satellites have diminished as capacity has grown. Commercial and Government satellites are regularly launched to serve both the military and civilian sectors. The United States has also established the Tracking and Data Relay Satellite System (TDRSS) for relaying communications between spacecraft and ground control.

NASA is now building the Advanced Communications Technology Satellite (ACTS) to demonstrate new technologies for communications satellites generally. The program was controversial for years because the Reagan Administration believed that the private sector should fund this research, while Congress consistently supported the view that such activities are too expensive for the private sector to pursue alone, and that in order to maintain U.S. competitiveness in these technologies, Government support is needed. The private sector is paying for part of the ACTS program, but the majority of the funding is from NASA.

The United States initiated creation of the International Telecommunication Satellite Organization (INTELSAT), established in 1964 to provide for an international communication satellite system. By the end of 1989, 118 countries were members of INTELSAT. The success of INTELSAT spawned creation of the International Maritime Satellite Organization (INMARSAT) in 1979 for maritime communications and it now has 55 members. The Soviet Union does not belong to INTELSAT (although it uses the system), but is a member of INMARSAT.

The Soviets established the first domestic communications satellite system (as opposed to an international system like INTELSAT) beginning in 1965. The Soviets used a different approach to communications satellites, deploying their Molniya satellites in highly elliptical orbits with an apogee of approximately 40,000 kilometers over the northern hemisphere and a perigee of approximately 500 kilometers over the southern hemisphere, rather than in geostationary orbit. This provides a long linger time over the northern hemisphere (8 hours), and four of these satellites can provide 24 hour coverage within the Soviet Union. The Molniya type of orbit is better than geostationary orbit for communicating at high latitudes where the curvature of the Earth makes it difficult for signals to reach from the Equator.

Although the Molniya orbit is good for internal communications in the Soviet Union, geostationary satellites are better for international communications and in 1974, the Soviets launched their first geostationary satellite. Since then, they have developed three different geostationary satellite systems: Raduga (1975), Ekran (1976), and Gorizont (1978). They have also launched geostationary satellites with experimental systems using higher frequencies. The Soviets have also filed a notice with the International Telecommunication Union for a satellite system called GALS which is thought to be for military communications, although none of this series has been launched yet. The Soviets are developing their own data relay satellites, and have used them (beginning in 1986) for data relay between their space station Mir and ground control. The Soviets have also retained the old store/dump type of communications satellite for tactical and theater operations.

Instead of joining INTELSAT, the Soviet Union formed INTERSPUTNIK in 1971 as a competitor. At the end of 1989, 15 countries were members of INTERSPUTNIK.

Many countries have their own dedicated communications satellites (in addition to using the INTELSAT system). After the Soviets, Canada was next to have a domestic communications satellite system, followed by the United States. Japan, India, Europe (collectively and individual countries), Indonesia, China, Mexico, Brazil, Australia, and the members of the Arab League are among those who have bought and/or launched their own communications satellites.

NAVIGATION

The United States has a navigation satellite system operated by the U.S. Navy. Originally called Transit, it was renamed the Navy Navigation Satellite System (the satellites are sometimes called Oscar) and provides two-dimensional data (latitude and longitude). The system is widely used by the civil sector in addition to its primary purpose of supporting military users.

In order to provide three-dimensional data (latitude, longitude, and altitude) 24 hours a day, anywhere on the globe, in all weather conditions, the United States is developing the NAVSTAR Global Positioning System. NAVSTAR GPS entered the testing phase in 1978 when four satellites were in orbit (the system ultimately requires a total of 18 satellites of which four must be in view of the user at one time in order to make the needed measurements). NAVSTAR GPS will replace the Transit system once it is operational, currently expected in the early 1990s.

The Soviet Union has indicated that it has a navigation satellite system called "Tsikada," although no satellite has had that designation, and in 1989 they launched a civilian navigation satellite designated "Nadezhda," which seems to be the same series. Except for that one satellite all Soviet navigation satellites are designated under the broad Cosmos label. The Tsikada/Nadezhda system is thought to be similar to Transit.

The Soviets are also developing a three-dimensional navigation satellite system like NAVSTAR. Their system is called "GLONASS," and the satellites are launched three at a time. In 1989, two GLONASS launches involved only two GLONASS satellites, while the third in each case was a geodetic satellite designated Etalon. GLONASS satellites have been launched since 1982, but these are thought to be part of a developmental program. It is not known when the system will be operational.

GEODESY AND MAPPING

The United States has flown many geodetic flights in the interest of tying together maps of different parts of the world and for basic scientific studies to understand better the true shape of the planet. (Such data are needed for many purposes, including missile targeting.) If there have been mapping flights as well, the results have not been published.

The Soviet Union is interested in both geodesy and mapping, but has made few public statements about such flights. Some flights in the Cosmos series have orbital characteristics which would support such missions. As noted above, two Etalon geodetic satellites were launched in 1989 in conjunction with GLONASS launches.

SEARCH AND RESCUE

In 1984, the Soviet Union and the members of SARSAT (the United States, Canada and France) signed an agreement providing for the operational phase of the COSPAS/SARSAT system which is used to locate ships and aircraft in distress. Transponders on Soviet navigation satellites and U.S. NOAA weather satellites pick up signals from emergency locator transmitters on ships and aircraft and relay them to ground stations and control centers in the Soviet Union, United States, Canada, France, Norway and Britain. The Soviet transponders are developed by the Soviets themselves and are called COSPAS; the transponders on the U.S. satellites are developed cooperatively by the United States, France, and Canada and are called SARSAT. INMARSAT serves as the secretariat for COSPAS/SARSAT.

METEOROLOGICAL SATELLITES

The United States has an operational weather satellite system using two satellites in Sun-synchronous polar orbits (called NOAA for the National Oceanic and Atmospheric Administration which operates them), and two Geostationary Operational Environmental Satellites (GOES) in geostationary orbit. (Each time a satellite in a Sun-synchronous orbit passes over any given location on Earth, it is precisely the same time as when it last passed over that site, e.g., 9:30 a.m., thus providing data with the same Sun angles which makes analysis of the data much easier.) NASA developed a low-cost ground terminal for receiving data from the polar orbiting satellites, called APT (automatic picture transmission) equipment, which is now available through a variety of companies to anyone in the world. The U.S. Department of Defense has its own polar orbiting weather satellites, called the Defense Meteorological Satellite Program (DMSP).

The Soviet Union has polar orbiting weather satellites called Meteor, but these are not in Sun-synchronous orbits. The Soviets do not have geostationary weather satellites, although they had promised to launch such a satellite as part of an international weather program in 1979. Their current plans for the program, called GOMS, are unknown. In 1988, they launched a satellite with the generic Cosmos designation (Cosmos 1940) that has a meteorological role, but apparently it is not GOMS.

REMOTE SENSING

Remote sensing satellites are designed to look down at the Earth from space. Although weather satellites also fall into the category of remote sensing, the term is more often applied to satellites that provide data on mineral deposits, pollution sources, crop forecasting, land management, or the oceans, for example.

Since 1972, the United States has launched five Landsat satellites for land remote sensing. Data from the Landsat spacecraft are available on a non-discriminatory basis to anyone for a fee. The first three Landsats had 80 meter resolution; Landsat 4 and 5 have 30 meter resolution (resolution is the ability to "see" an object, so a 30 meter resolution means that you can detect objects larger than 30 meters in diameter).

The U.S. Government decided not to launch any more Landsat satellites, expecting the private sector to take over the program since the technology had become mature. Legislation passed Congress in 1984 (P.L. 98-365) to facilitate transfer of the remote sensing program to the private sector. The Department of Commerce (which has operational responsibility for the Landsat series) selected a contractor, EOSAT, to commercialize the system, but the so-called "privatization" of Landsat has been complicated by disputes between the Executive Branch and Congress over promised Government subsidies to EOSAT. The issue was especially controversial in 1989, and was reviewed by the National Space Council which decided that the U.S. Government would support the Landsat program, though few specifics were announced. France, which developed the SPOT satellite with 10 meter resolution, and the Soviets (see below) also offer remote sensing data on a commercial basis.

The United States also pioneered in ocean remote sensing. In 1978, SEASAT was launched carrying a synthetic aperture radar and other instruments to make oceanographic observations and measurements (ocean waves, ice fields, coastal conditions, surface temperature, and others). The spacecraft suffered a malfunction after only 100 days in orbit, however. Similar radars were flown on the space shuttle (SIR-A and SIR-B) and additional flights are planned. The shuttle can stay in orbit for only 7-10 days, however. Attempts to build a follow-on to Seasat failed because of budgetary considerations. NASA developed an instrument, called a scatterometer, that was to have flown on one of the proposed follow-on satellites. That instrument, now designated NSCAT (NASA Scatterometer), is expected to be flown on a Japanese spacecraft called ADEOS in 1995. NASA is also working on the TOPEX (Ocean Topography Experiment) program in conjunction with France.

The Soviet Union has developed a great interest in remote sensing. Crews on Salyut 6 and 7 from 1977-1986 (as well as other Soviet space stations) spent a considerable amount of time performing Earth resources investigations with a variety of cameras, including a six channel multispectral camera (MKF-6M) developed by East Germany. Although the MKF-6M is not installed on the new Mir space station, the crews do perform some remote sensing observations using hand held cameras and a topographic camera called KATE-140, which was also used on Salyut. The Soviets plan to launch a module to dock with Mir that is devoted to remote sensing studies.

The Soviets also have launched several experimental Landsat-type satellites in the Resurs-O series. A third series of remote sensing flights, Resurs-F, uses satellites that are indistinguishable from military reconnaissance flights in terms of orbital parameters and lifetimes. The spacecraft remain in orbit for only two weeks, after which they are recovered, suggesting that they are using film. Although some Western analysts count these as reconnaissance rather than Earth resources missions, this report classifies them as remote sensing since there is no logical reason for the

Soviets to specify that these flights, in particular, are for remote sensing, when ordinarily they would simply say nothing about their mission.

In 1987, the Soviets launched a large satellite, Cosmos 1870, or Resurs-R, which they stated was devoted to remote sensing observations. It carried a synthetic aperture radar, but little information is available about other instruments on board. The satellite was about the same size as a Salyut space station (or the Mir core module) and flew in a relatively low orbit during its two years of operation. Additional satellites in this series are planned. The Soviets have launched several satellites with side-looking radars for remote sensing of the oceans and especially for guiding ships through the Arctic Ocean; these are designated Okean-O.

The Soviet Union has begun marketing data from its land remote sensing satellites with five meter resolution, better than that available from Landsat or the French SPOT satellite. One Soviet organization charged with responsibility for selling the data is called Soyuzkarta. The Soviets originally stated that they would sell data only about the country where the buyer is located (i.e., a U.S. citizen could only buy data about the United States). This position apparently has changed with time. In late 1988, the Soviets signed a contract with Contitrade (a subsidiary of Continental Grain) to represent Soyuzkarta in most of the Western hemisphere and a Contitrade official has said that data are available on any country outside the Soviet bloc, China and Afghanistan. Another American company, Space Commerce Corporation, has an agreement with the Soviet Glavkosmos agency to sell remote-sensing data, as well.

MISSION TO PLANET EARTH

NASA and the world's scientific community are initiating a program called Mission to Planet Earth (MPE), which will provide data to help scientists better understand the Earth as a total system and what effect the human population has on the planet. Generically, this field of study is called "Global Change" research and includes such topics such as global warming, ozone depletion, and deforestation. The international scientific effort to study Global Change is called the International Geosphere-Biosphere Program (IGBP).

NASA defines MPE as certain satellites and associated data systems needed to provide data for the Global Change program. Ultimately, NASA plans to have four large, multipurpose spacecraft called "platforms" in polar orbit (around Earth's poles), five platforms in geostationary orbit (35,800 kilometers above the Equator, where a satellite maintains a fixed position relative to any point on Earth), plus a variety of other satellites in different orbits from which special observations can be made (called "Earth Probes"). The geostationary platforms are not part of NASA's current budget plans. Thus, NASA now defines MPE as the polar platforms (called the **Earth Observing System**), the Earth Probes, and associated data systems. NASA plans to provide two of the polar platforms (until 1989 they were part of the space station program, but now are separate), with the third from Europe, and the fourth from Japan. These countries and others (including the Soviet Union), individually or cooperatively, are planning other spacecraft that will contribute data to the Global Change research program. For example, the U.S. Upper Atmosphere Research Satellite (UARS), the U.S./French Ocean Topography Experiment (TOPEX), the European Earth Remote Sensing (ERS) satellite, the Japanese ERS (JERS) satellite and Advanced Earth Observing System (ADEOS) platform are all related to studies of the Earth and its environment. (See CRS Issue Brief 87108, *Space Policy*, for further information on Mission to Planet Earth. A CRS Report on this topic is also expected to be available in the spring of 1990.)

CHAPTER 4

SPACE SCIENCE

Both the United States and the Soviet Union have sent probes to fly-by, orbit, and/or land on other planets. Other probes investigate the interplanetary medium and/or comets. So far, the United States has sent probes to Mercury, Venus, the Moon, Mars, Jupiter, Saturn, Uranus, and Neptune. The Soviet Union has sent probes to Venus, the Moon, and Mars. A U.S. probe already in space was diverted to investigate a comet in 1985; two Soviet probes intercepted Halley's Comet in 1986 (along with spacecraft from Japan and Europe). The United States and Soviet Union also have extensive programs for studying Earth's atmosphere, the interaction between the Earth and the Sun (solar-terrestrial relationships), and the universe using spacecraft in earth orbit.

EARTH-ORBITAL SPACE SCIENCE

The history of Earth-orbiting satellites for space science studies began with the very first launches of spacecraft. As discussed at the beginning of this report, the decision to launch satellites was made as part of the International Geophysical Year (IGY), and both Sputnik 1 and Explorer 1 were launched in support of the IGY.

The United States has conducted a large number of launches of Earth-orbiting space science missions. The Explorer program is a continuing series of small satellites devoted to a particular scientific goal. Many of the Explorer missions involve international participation, and by the end of 1987, over 60 Explorer satellites had been flown. Some study the interaction between the Sun and Earth in disciplines such as air density, energetic particles, ionospheric research, magnetospheric research, and solar physics. Other Explorer satellites are dedicated to astronomy, including wavelengths in the x-ray, gamma-ray, ultraviolet, and radio ranges. Larger observatory-class satellites have also been launched by the United States. To date, these have included the Orbiting Geophysical Observatory (OGO), Orbiting Solar Observatory (OSO), Orbiting Astronomical Observatory (OAO), and High Energy Astronomy Observatory (HEAO) programs. The next U.S. observatory-class spacecraft scheduled for launch is the Hubble Space Telescope, which will be the first optical telescope in orbit. It is now scheduled for launch on the shuttle in April 1990.

The Soviet Union launched its first geophysical observatory in 1958 (Sputnik 3), but has not used Earth orbit as a base for free-flying scientific spacecraft as extensively as the United States. Most Soviet scientific satellites are designated simply as Cosmos flights and few details are released about them. There is a subset of these, however, developed under the Interkosmos program cooperatively with other countries (primarily Soviet-bloc countries), for which results are more widely distributed.

The Prognoz program, of which there have¶29Xb10 flights since 1971, is the closest the Soviets have come to observatory-class spacecraft performing multiple missions. The first eight of these concentrated on atmospheric studies, and Prognoz 10 made magnetospheric studies. Prognoz 9, launched in 1983, performed radio astronomy research. Also in 1983, the Soviets launched the Astron satellite, a large observatory-class satellite which performed research in the x-ray and ultraviolet wavelengths. Granat, launched in 1989, will continue astronomical research in the x-ray and gamma ray bands.

Space science research has also been conducted on the space stations launched by both the United States and Soviet Union. For example, the U.S. Skylab carried the Apollo Telescope Mount dedicated to studies of the Sun, and a radio telescope was deployed from the Soviet Salyut 6. For the Soviets, the launch of the Kvant module to Mir in 1987 ushered in a new era of space station astronomical observations. Kvant incorporates instruments for both gamma-ray and x-ray astronomy, and the module appears to be a permanent part of the space station complex. During 1987, the Soviets made many observations of the supernova in the Large Magellanic Cloud discovered by ground-based observers at the Cerro-Tololo Observatory in Chile. The Soviets also perform wide-ranging atmospheric studies using instruments on their space station.

AUTOMATED LUNAR EXPLORATION

The first attempts to send spacecraft to the Moon were either fly-bys or probes that were intended to strike the Moon without surviving the impact. In 1958, the United States began a double series of Pioneer flights--one to photograph the far side of the Moon and the other to fly by it. All four launch attempts in that year failed to reach the Moon. In January 1959, the Soviets launched Luna 1 which apparently missed the Moon. The United States followed in March 1959 with Pioneer 4 which went by the Moon and circled the Sun. U.S. plans then were to follow up with four more, larger Pioneer series lunar orbit flights during the course of 1959 and 1960, but all of these failed to reach even Earth orbit. In fact, a U.S. probe did not reach the Moon until Ranger 4 impacted the far side in 1962.

In September 1959, the Soviet Luna 2 struck the Moon near its visible center, delivering metal plaques bearing the Soviet coat of arms. In October 1959, Luna 3 flew by the Moon and took photographs of the far side, never seen before, which were returned to Earth by radio facsimile. Still later, the U.S. Ranger 7, 8, and 9 flights (1964-1965) returned spectacular TV pictures of the Moon up to the moment that they impacted the lunar surface.

The next phase of automated lunar exploration used spacecraft to make survivable landings. The seven U.S. Surveyor spacecraft (1966-1968) returned almost 100,000 pictures of the lunar surface and dug holes in the surface by remote control to determine the chemical composition of the lunar soil.

The Soviet Union attempted landings as early as 1963, but later admitted that Luna 4, 5, 6, 7, and 8 failed to achieve a survivable landing. Additionally, one unnamed flight and Cosmos 60 were lunar failures which did not leave Earth orbit. When Luna 9 in 1966 finally reached the surface, its television camera returned 27 pictures of the surroundings--the first pictures from the surface of another solar system body. Luna 13 performed impact testing of the soil with an extendable arm.

Orbiters were used at about the same time as the landers. The Soviet Luna 10 was the first spacecraft to achieve a successful lunar orbit (1966) and returned data about the composition of the lunar surface and gravity anomalies. Luna 12 in 1966 finally returned a few pictures to supplement earlier Soviet pictures taken of the far side by Luna 3 in 1959 and Zond 3 in 1965. Luna 14 (1968) was an extension of the work of Luna 10, neither of which took pictures. The five U.S. Lunar Orbiters (1966-1967) returned extensive data about the lunar surface that were used to select landing sites for the Apollo missions.

The Apollo landings (see chapter 2) followed the U.S. automated lunar program, and no further automated lunar missions have been launched by the United States. The Soviets continued to launch lunar probes until 1976. Zond 5 and 6, the 1968 automated precursors to projected later piloted flights, returned actual photographs to Earth in the same manner as Apollo 8. Zond 7 in 1969 and Zond 8 in 1970 performed tasks similar to those of the two preceding Zonds. Heavier satellites were placed in lunar orbit (Luna 19 in 1971 and Luna 22 in 1974) which remained under active control for more than a year, gathering a wide variety of data and some pictures.

The Soviet Union launched two special types of lunar vehicles for exploration of the Moon in lieu of human crews. Three missions (Luna 16 in 1970, Luna 20 in 1972, and Luna 24 in 1976) returned a total of approximately 330 grams of lunar material to Earth (compared with 380 kilograms returned by the U.S. Apollo crews). Three other flights that may have been intended to return samples failed (Luna 15, 18, and 23).

The other special Soviet program placed roving vehicles called Lunokhods on the lunar surface. Lunokhod 1 (Luna 17) landed on November 17, 1970, and continued to function until October 4, 1971, traveling 10,540 meters over the surface, and returning 20,000 television views, 200 detailed panoramas, 500 soil-property tests, 25 soil chemical analyses, and a number of astronomical observations with its x-ray telescope. Lunokhod 2 (Luna 21) in 1973 operated for 3 months, but traveled 37,000 meters in that time, and returned proportionately more data and pictures despite its shorter life.

U.S. PLANETARY MISSIONS

The U.S. Mariner program of three-axis stabilized probes involved the launch of ten vehicles, six of which returned planetary data. Mariner 2 and 5 brought back indirect readings of Venus. Mariner 4, 6, 7, and 9 brought back increasingly good pictures of the surface features of Mars. Mariner 10 not only returned good pictures of the cloud patterns of Venus, but made three photographic passes by Mercury.

The Pioneer series of spin-stabilized spacecraft has seen 18 launch attempts, of which 12 were at least partially successful. Pioneer 1 and 3 did not reach their intended trajectories to the Moon, but did send back data about Earth's atmosphere. Pioneer 4 successfully returned data as it flew past the Moon and entered heliocentric orbit. Pioneers 5 through 9 studied the area of space between the Earth and Sun.

Pioneers 10 and 11 were the first planetary probes of the Pioneer series, and were launched to investigate Jupiter, Saturn, and the interplanetary medium. Both probes sent back pictures of Jupiter in 1973 and 1974 respectively; Pioneer 10 then was placed on a trajectory out of the solar system, while Pioneer 11 continued on to a successful encounter with Saturn in 1979. In 1983, Pioneer 10 passed out of the solar system, the first object from planet Earth to do so, and continues to return data.

Pioneer Venus 1 and 2 were launched in 1978 and reached Venus in December of that year. Pioneer Venus 1 is an orbiter, which continues to return data about Venus, and in 1986 also was used to collect data about Halley's Comet. Pioneer Venus 2 consisted of five separate probes, all of which descended through the Venusian atmosphere to make in situ measurements of its characteristics. Although they were not designed to withstand landings on the planet, two of the probes did survive and transmitted data for as long as 67 minutes after impact.

Viking 1 and 2, launched in 1975, each were orbiter/lander combinations. The orbiters mapped the surface of Mars and collected clear views of Deimos and Phobos, the two Martian moons. The landers sent back color pictures from the surface, and their on-board laboratories conducted a search for life with inconclusive results. The last of the Viking spacecraft (the Viking 1 orbiter) returned data until 1983. NASA has now turned ownership of that lander over to the Smithsonian Museum.

Voyager 1 and 2 were launched in 1977 toward Jupiter and the outer planets. During 1979, they returned astonishing color pictures not only of Jupiter, but also of its larger moons, each unique and unexpected in appearance. In 1980, Voyager 1 returned equally exciting pictures of Saturn and its moons, including Titan, and Voyager 2 returned data on Saturn in 1981. Voyager 2 reached Uranus in January 1986 and Neptune in August 1989, returning more data to astound Earth-bound scientists.

In 1989, NASA launched the Magellan mission to Venus, where it will arrive in August 1990 to make detailed radar maps of the surface. NASA also launched the Galileo probe to Jupiter in 1989; it will arrive there in 1995. One section of the spacecraft will descend through Jupiter's atmosphere, while another will orbit the planet and then make a tour of several of Jupiter's moons.

The United States has had several probes to investigate the interplanetary medium. One of special note was launched in 1978 as International Sun-Earth Explorer 3, part of a series of satellites for studying solar-terrestrial relationships. In 1983, it was redesignated ICE, or International Cometary Explorer, and was moved from its position between the Earth and the Sun to fly by Comet Giacobini-Zinner in September 1985. Data from this encounter is being compared with that obtained by other spacecraft about Comet Halley. The United States did not have a probe for the Halley's Comet encounter.

SOVIET PLANETARY MISSIONS

In 1961, the Soviets launched their first Venus probe, Venera 1, but it was not operating when it reached the planet. In 1962, there were three more Venus attempts and three Mars attempts, with five of these payloads stranded in Earth orbit, and the sixth, Mars 1, not operating when it reached the vicinity of that planet. Zond 1, Venera 2, and Venera 3 were not in operating condition when they reached Venus. Zond 2 made a close fly-by of Mars in a non-operating condition. Zond 3 was a test flight which took pictures of the far side of the Moon and rebroadcast them to Earth as it traveled as far as the orbit of Mars.

Results improved for the Soviets when Venera 4, 5, 6, 7 and 8 all functioned and returned direct readings of Venus' atmosphere. Venera 7 survived a Venus landing and broadcast for 23 minutes from the surface. Venera 8 had similar success, plus performing soil analyses.

In 1975, two larger Soviet Venus probes, Venera 9 and 10, reached their destination and became the first spacecraft to return pictures from the surface of another planet. The orbiters returned pictures and other data for many months in orbit. The landers operated for about an hour on the surface, and their cameras returned good pictures of the far side surface, relayed via the orbiters. This was a remarkable feat, considering the 485°C temperature and surface pressure 90 times that on Earth.

Venera 11 and 12 were sent to Venus in 1978, at approximately the same time as the U.S. Pioneer-Venus probes. No photographs were returned by these spacecraft, and Soviet scientists have indicated that the imaging systems failed. Data were returned on other aspects of the Venusian atmosphere and surface. Venera 13 and 14 landed in 1982 and sent back color photographs of the surface, and used drills to obtain core samples for chemical analysis.

In 1983, the Soviets launched Venera 15 and 16 which, instead of carrying the traditional landers, were equipped with side-looking radars to study the surface of Venus from orbit. Venera 15 entered orbit around Venus on October 10, followed four days later by Venera 16. The radars had a resolution of 1-2 kilometers, and were in polar orbits around the planet to provide data on parts of the planet not seen by the U.S. Pioneer-Venus orbiter or from Earth-based telescopes.

In December 1984, the Soviets launched two VEGA spacecraft to study both Venus and Halley's Comet. At Venus, the two spacecraft dropped off landers and balloons developed by French scientists which slowly drifted through Venus' atmosphere to make in situ measurements. The main part of each spacecraft continued on to an encounter with Halley's Comet in March 1986. VEGA 1 was the first probe to arrive there; others were launched by the European Space Agency and Japan.

The Soviets have been plagued with problems in their Mars program. In 1971, two orbiter/lander spacecraft, Mars 2 and 3, were launched. Mars 2 landed on the surface but no further mention was made of it by the Soviets, suggesting that it failed. Mars 3 made a survivable landing, but signals ceased after 20 seconds, before the first complete picture was received on Earth. The orbiters did return data. In 1973, four spacecraft (Mars 4, 5, 6 and 7) were launched. Mars 4 and 5 were intended as orbiters working with the Mars 6 and 7 landers. Of these four only Mars 5 attained an orbit and Mars 6 a landing. Mars 6 returned direct readings within the atmosphere, but signals ceased before it reached the surface. Thus, of all these missions, only Mars 5 can be counted as a complete success by Western standards.

In June 1988, after a 15 year hiatus in sending probes to Mars, the Soviets launched two Mars probes, Phobos 1 and 2. The spacecraft included a large number of international experiments, and were almost identical. The primary objective for the Phobos project was to study Phobos, one of the two moons of Mars, although studies also were to be made of Mars itself. The bad luck indicative of the Soviet Mars exploration program evidenced itself with this project as well. On August 29, 1988, a Soviet ground controller sent an incorrect command to Phobos 1, telling it to turn off its stabilization systems. The error was not detected until three days later when attempts at contacting the spacecraft were unsuccessful. The Soviets speculate that with the attitude stabilization system turned off, the spacecraft no longer maintained its correct orientation toward the Sun to keep the batteries charged, and the spacecraft died.

Phobos 2 continued its journey to Mars uneventfully, reaching Martian orbit at the end of January 1989. The probe successfully returned data about Mars, but as it was maneuvering to make its studies of Phobos, contact was lost with the spacecraft. The Soviets have narrowed the cause to three possibilities, but feel they may never know exactly what happened. Thus, Phobos 2 failed in its primary objective (studying Phobos), but was successful in returning data about Mars and thus is categorized as a partial success.

FUTURE U.S. AND SOVIET SPACE SCIENCE MISSIONS

The U.S. space science program continues to recover from the 1986 space shuttle *Challenger* tragedy. Three major space science missions--the U.S. Hubble Space Telescope, the U.S. Galileo mission to study Jupiter, and the European Ulysses probe to investigate the polar regions of the Sun--were to have been launched on the shuttle in 1986. Galileo was launched in 1989, and the Hubble Space Telescope and Ulysses are now scheduled for launch in 1990.

The Hubble Space Telescope is the first of four "great observatories" NASA plans to launch to study the universe at different wavelengths. The second in the series is the Gamma Ray Observatory, currently scheduled for launch in late 1990. NASA has initiated development of the Advanced X-Ray

Astronomy Facility (AXAF), the third in the series. The last is the Space Infrared Telescope Facility (SIRTF) for launch sometime in the 1990s.

More Explorer satellites are also being planned by NASA, and Congress has increased funds for the Explorer program in recent years to provide more flight opportunities for scientists (the satellites are relatively inexpensive and easy to produce compared to observatory-class spacecraft). EUVE (Extreme Ultraviolet Explorer) and XTE (X-Ray Timing Explorer) are planned next.

An international armada of Earth-orbiting satellites is being planned to support the International Solar-Terrestrial Physics (ISTP) program to further study the interaction between the Sun and the Earth. The U.S. contribution to ISTP is called the Global Geospace Science (GGS) program and involves the launch of two spacecraft called Wind and Polar. As part of ISTP, the Japanese and Europeans will each also build two spacecraft (Geotail and CRRES, and Cluster and SOHO respectively). All are scheduled to be launched in 1992-1993.

In 1992, the United States plans to launch Mars Observer, a probe for geophysical and climate studies of Mars. Two new planetary missions were begun in 1989: the Comet Rendezvous-Asteroid Flyby Mission (CRAF) and Cassini, to study Saturn and its moon, Titan. The two probes will use the same spacecraft design and were requested jointly by NASA, so are"36Xoften referred to as though they were one project--CRAF/Cassini.

Magellan, Mars Observer, CRAF and Cassini were all recommended as the "core program" by NASA's Solar System Exploration Committee, which issued two reports (in 1983 and 1986) on the future of U.S. planetary exploration. NASA relies on internal and external advisory committees to prioritize space science objectives. In addition to its own SSEC, NASA uses the National Academy of Sciences to prepare advisory reports. In 1988, for example, the Academy released a 7-volume study entitled *Space Science in the 21st Century: Imperatives for the Decades 1995-2015*. The missions identified in these committee reports are proposals, not approved programs; it is up to NASA to ultimately decide which programs to request funding for and in what order.

In October 1987, at celebrations marking the 30th anniversary of the launch of Sputnik, the Soviets announced broad proposals for planetary exploration that caused great concern among their Western colleagues. Although the Soviets emphasized that they were only proposals, not plans, some Western planetary scientists characterized the Soviet announcement as an indication that the Soviet Union was achieving a leadership position in planetary exploration.

In the intervening years, the Soviet proposals have been changed and scaled down considerably, probably because of additional discussions inside the Soviet planetary science community, coupled with the expectation of difficult budget times ahead. In August 1989, the Soviets listed the following missions as possibilities for the next 15 years, although they again stressed that only the Mars '94 mission was close to being formally approved: Mars '94, to orbit Mars and to deploy French-made balloons for studies of the planet itself; Mars-Aster '96, to fulfill some of the objectives of the Phobos missions and to study the asteroid belt; Mars '98, to land rovers on Mars; Mars 2001, to return samples of Martian soil to Earth; and an unnamed mission to Mercury in 2003.

Many scientists are interested in the possibility of U.S./Soviet cooperation in space. One specific proposal is that the United States send a rover to Mars that would roam about the surface collecting samples from various locations. The rover would bring the samples back to a Soviet spacecraft that would return them to the vicinity of Earth for analysis (they probably would not be brought back to Earth itself because of contamination concerns). This is not yet an approved mission by either country, although each is conducting independent rover/sample return design studies. From the U.S. standpoint, a joint mission would avoid many problems such as technology transfer, since the only place the probes need to be compatible is on the surface of Mars. Also, if either country withdrew from the program for economic, technical, or political reasons, the other would still have a viable scientific mission.

The Soviets are also planning additional Earth-orbiting scientific satellites. Among them are: Gamma 1, the long-delayed Soviet/French gamma ray astronomy satellite (originally scheduled for launch in 1985, and currently planned for the spring of 1990); Interbol, a magnetospheric research mission which will involve the launch of two satellites, each with a Czechoslovakian sub-satellite, in 1990-1991; CORONAS (comprehensive study of solar activity from near-earth orbit) for launch in 1990-1992 to study solar eruptions; Spectrum-X/Gamma for observations in the ultraviolet, x-ray and gamma ray bands, for launch in 1993 (20 countries, including the United States, are participating in this project); and Radioastron, a group of three radio astronomy satellites planned for launch in 1995-1997.

CHAPTER 5

MILITARY SPACE ACTIVITIES

MILITARY VERSUS CIVIL SPACE MISSIONS

There is little difference between the Soviet and U.S. space programs as to their general purpose and direction. Both include scientific exploration, technology development and practical applications, using piloted and automated spacecraft. The satellites support both the military and civilian sectors.

The distinction between military and civilian launches is arbitrary to a certain extent, since any satellite can be used for either sector. For example, communications satellites can carry either military or civilian traffic, and navigation satellites are used by both the military and civilian communities.

When attempting to construct a list of military versus civilian launches, such as table 4, determining which sector will be primarily served by a satellite is complicated. The Soviets, for example, ordinarily do not announce the mission of satellites designated "Cosmos" which comprise a substantial fraction of their annual launches. Western analysts of the Soviet program assess the mission of these satellites based on factors such as telemetry, past experience, and the likely nature of a satellite using a particular orbit. In the United States, missions for DOD satellites are rarely revealed and even when they are, categorizing them as military or civilian can be complex. For example, Transit navigation satellites are developed by the Navy for its own use, but more than 90 percent of the system's users are civilian. Clearly, distinguishing between military and civilian satellites is an inexact art.

The process is even more difficult since table 4 reflects launches rather than individual satellites. The U.S. space shuttle may launch several payloads at one time, and other experiments may take place on the shuttle itself. A Defense Satellite Communications System (DSCS) communications satellite launched from the shuttle would be classified as military, but if the predominant nature of the shuttle mission is civilian, it will be listed as a civilian launch in the table. Only those shuttle missions dedicated to DOD use are counted as military. These difficulties should be borne in mind when using the table.

MILITARY SPACE PROGRAMS

Military satellites are, for the most part, non-aggressive. In fact, their missions are hardly distinguishable from missions conducted for civilian application purposes. Both countries have military satellites for communications, weather, navigation, geodesy, and various types of reconnaissance (photographic, electronic intelligence, nuclear explosion detection, early warning, and ocean surveillance).

The only generic type of satellite that the Soviets have for which there is no corresponding U.S. system is radar ocean reconnaissance satellites (RORSATs) which use radars to monitor the oceans (although unconfirmed press reports assert that the United States launched a radar satellite, Lacrosse, in 1989). The Soviet radars require a great deal of power and the Soviets use nuclear reactors on the satellites to provide that power. For safety reasons, the portion of the satellite containing the nuclear reactor is separated from the rest of the spacecraft after the mission is over and boosted

TABLE 4. Approximate Comparison of U.S. and Soviet Successful Launches: Primarily Civil Versus Primarily Military*

YEAR	PRIMARILY CIVIL		PRIMARILY MILITARY	
	U.S.	U.S.S.R.	U.S.	U.S.S.R.
1957	0	2	0	0
1958	5	1	0	0
1959	5	3	5	0
1960	6	3	10	0
1961	10	6	19	0
1962	21	15	31	5
1963	12	10	26	7
1964	25	15	32	15
1965	35	23	28	25
1966	41	17	32	27
1967	34	20	24	46
1968	25	25	20	49
1969	24	19	16	51
1970	14	26	15	55
1971	22	23	10	60
1972	20	21	11	53
1973	15	28	8	58
1974	18	29	6	52
1975	21	29	7	60
1976	19	25	7	74
1977	15	29	9	69
1978	24	28	8	60
1979	12	27	4	60
1980	8	25	5	64
1981	13	39	5	59
1982	12	33	6	68
1983	15	40	7	58
1984	10	34	12	63
1985	11	33	6	64
1986	3	28	3	63
1987	2	33	6	62
1988	6	37	6	53
1989	5	32	13	42
TOTAL	508	758	397	1,422

* See text for cautionary statements about use of this table.

Prepared by CRS.

into a high orbit from which it will not return to Earth until the radioactivity has subsided (hundreds of years). In two cases, however, the system malfunctioned. In 1978, Cosmos 954 reentered prematurely and spread radioactive material over northern Canada. In 1983, Cosmos 1402 reentered in two pieces over the Indian Ocean and the South Atlantic. No increase in radioactivity was detected in either area. There was another RORSAT malfunction in 1988 (Cosmos 1900). In April, the Soviets lost communication with the satellite, and could not command the reactor portion to be boosted into the higher orbit. In October, as the orbit decayed and the satellite reached the dense layers of the upper atmosphere, a fail-safe system was automatically triggered and the reactor was, in fact, boosted to the "safe" orbit. No RORSATs have been launched since.

Although the U.S. Government is reluctant to talk about military space activities, a considerable amount of information has appeared in the public literature. In some cases, Government officials have given public statements concerning these activities as well. For example, on March 15, 1967, President Johnson, speaking in Nashville, Tennessee asserted in an "off-the-record" statement widely reported at the time that the dividends of military space operations to the United States were equal to ten times everything which had been spent on space. This implied savings in the defense budget over a ten year period on the order of $400 billion, because of more precise information about military and related activities all over the world. President Carter on October 1, 1978, officially acknowledged the U.S. role in military photoreconnaissance from space.

The Soviets publicly acknowledged the existence of their military space program in 1985, but are also reticent to discuss it in detail. *Glasnost* and the need to justify space expenditures apparently is affecting even military programs, however, and some information is now forthcoming. In May 1989, a Soviet official stated that one of the uses for the space shuttle Buran could be to service "optoelectronic and radar reconnaissance satellites." Two months later, the Defense Ministry's chief specialist on missile and space systems, A. Maksimov, discussed the value of the Soviet military space program in an interview with *Krasnaya Zvezda*. Maksimov stated that reconnaissance satellites have 0.2-0.3 meter resolution, meaning "that from orbit it is possible . . . to determine whether a bomber of the B-1 type is equipped with missiles . . . ." He added that "the implementation of military space programs alone will enhance our Armed Forces' combat efficiency 50-100 percent. The role of national space reconnaissance means increase particularly with the adoption of a defensive doctrine."

SPACE WEAPONS

There is one special category of military space activities which can be described as "aggressive" and this is space weapons. Considerable debate has developed as to whether space weapons, either those based in space for use against ground, air or space targets, or those based in the air or on the ground for use against space targets, will lead to greater or less stability between the superpowers. Although they have become a matter of increasing debate in the past several years, space weapons have existed since the earliest days of the space program.

Early U.S. and Soviet Antisatellite Programs

The first test of an antisatellite (ASAT) device was conducted by the United States in 1959. A Bold Orion air-launched missile was used to score a deliberate near miss on the U.S. Explorer 6 satellite. Although the Bold Orion was not pursued as an ASAT device, the United States did have plans for a program called SAINT (variously described as having stood for SAtellite INspecTor, SAtellite INTerceptor, or SAtellite Inspection and NegaTion) from 1960-1962, but this program also was cancelled.

In 1962, Nikita Khrushchev stated in an interview with American newspaper editors that the Soviet Union had a missile that could "hit a fly in outer space." This was interpreted by some as an indication of an ASAT capability, perhaps using Galosh antiballistic missiles. Perhaps in response to this concern, or perhaps because of the FOBS program (see below), the United States developed its own ASAT system using missiles based on Johnston Island and Kwajalein Atoll in the Pacific. The system at Kwajalein, which used Nike-Zeus missiles, was terminated in 1964, while the Johnston Island system, using Thor missiles, was declared operational by President Johnson in a 1964 speech. These facilities are believed to have been shut down in 1975. Since the system employed nuclear warheads, its use would have violated the 1963 Limited Test Ban Treaty and the 1967 Outer Space Treaty. The Soviet Galosh system may still be capable of intercepting satellites to about the same degree as the United States could have from its mid-Pacific installation, and similarly would violate the 1963 and 1967 treaties if used.

The Soviet Co-Orbital ASAT Device

Beginning in 1968, the Soviets began testing a co-orbital ASAT device; a total of 20 tests have been conducted so far. The most recent test was in June 1982, and the Soviet Union subsequently announced a unilateral moratorium on ASAT testing, stating that it will not be the first to place ASAT weapons in orbit (but avoiding any admission that they have already tested an ASAT device). The interceptor is launched by a variant of the Cyclone (F) booster and goes into a close co-orbit with the target satellite. In operation, the interceptor would then maneuver close to the target and explode (using a chemical explosive), destroying the operational capability of the target with shrapnel. Nine of the 20 tests are counted as successes in the West.

Tests were conducted from 1968 to 1971, after which a four-year hiatus occurred. Testing resumed in 1976, the year after the U.S. dismantled its missile ASAT system, and the Chinese had orbited their first prototype reconnaissance satellite. Whether these factors led to the resumption in testing, or whether the Soviets introduced a system with new technology at that time, is unclear. The United States declared the Soviet system operational in 1977 and decided to develop its own advanced ASAT (see next section). At the same time, President Carter called on the Soviets to negotiate a treaty to ban weapons from space, and during the course of those talks in 1978-1979, the Soviets once again ceased tests of their ASAT device. When the negotiations ended (following the Soviet invasion of Afghanistan in late 1979), the ASAT tests resumed, with one test in 1980, two in 1981, and one in 1982. Whether or not this system should still be considered operational, after more than seven years of dormancy and a less than perfect success rate, is open to question.

The Soviet system is limited by the altitudes and inclinations at which it can be used. U.S. communications and early warning satellites are currently outside the range of the Soviet co-orbital ASAT, although future developments (such as using a more capable launch vehicle) could enhance its range.

U.S. F-15 ASAT Device

In 1977, following the Pentagon's assessment that the Soviet ASAT system was operational, President Carter authorized DOD to develop a U.S. ASAT device. Unlike the Soviet system, which is launched from the ground like a typical satellite, the U.S. decided to develop a system using a Miniature Homing Vehicle (MHV) launched from a two-stage rocket attached to an F-15 aircraft. With this mobility, it could go to the target satellite, rather than waiting for the satellite to be in a correct orbital position to be intercepted from a ground launch site. The MHV would destroy its target by direct impact, rather than carrying any explosive material.

The U.S. MHV ASAT system encountered stiff congressional opposition in the 1980s, and Congress placed limits on testing the system against objects in space until and unless the Soviets again tested their co-orbital system. Five U.S. tests were conducted: four (two in 1984 and two in 1986) against points in space; one (in 1985) against an object (an old U.S. satellite). In early 1988, DOD cancelled this program because of the congressional opposition.

Other Antisatellite Devices

Ground-based lasers apparently are under development by both the United States and the Soviet Union for ASAT purposes. The Pentagon asserts that the Soviets have at least one and possibly two ground based laser sites with the potential for damaging some components of U.S. satellites. In 1987, DOD initiated a ground-based laser ASAT program of its own which will build on activities conducted under the Strategic Defense Initiative (SDI) program. Ground-based lasers by themselves suffer two basic limitations as ASAT devices: they can only attack satellites as they pass nearly overhead, and atmospheric absorption decreases the intensity of the laser beam even in clear weather. The use of orbiting mirrors could provide more flexibility in targeting the laser beam, and very powerful lasers could mitigate atmospheric affects, however.

DOD lists other potential Soviet ASAT devices as direct ascent missiles (the Galosh antiballistic missile), electromagnetic interference (jamming), space-based directed energy (laser or particle beam) weapons, and space-based kinetic energy weapons.

The major U.S. ASAT effort today is development of ground-based kinetic energy weapons. The Army has been assigned the lead role in this program, and may use technology derived from the Strategic Defense Initiative ("Star Wars") program. DOD has stated that it wants a system to meet the "minimal" requirements established by the Joint Chiefs of Staff. A primary justification for a U.S. ASAT is the threat DOD believes is posed by Soviet radar ocean reconnaissance satellites (RORSATs) which are designed to track U.S. ships at sea. (For more information, see CRS Issue Brief 85176, *ASATs: Antisatellite Weapons Systems*.)

Soviet Fractional Orbital Bombardment System (FOBS)

Although no country has placed nuclear weapons in orbit to date, the Soviets tested a system from 1967-1971 called a Fractional Orbital Bombardment System (FOBS) which could be considered such a device if it had become operational. FOBS was essentially a long range ICBM which would have approached the United States from around the South Pole, rather than the North Pole, thus avoiding the Ballistic Missile Early Warning System (BMEWS) radars which point to the north. The tests were not technically a treaty violation because there is no reason to assume they carried nuclear material, and the dummy warhead flew less than one full orbit. The system apparently has since been dismantled.

CONCERNS ABOUT THE MILITARIZATION OF SPACE AND "STAR WARS"

In the early 1980s, concern began to grow about the apparent "militarization" of space, that is, the increasing use of space for military purposes, particularly weapons. As noted above, the 1978-79 negotiations initiated by President Carter to ban weapons from space were unsuccessful. In 1981, the Soviets introduced a draft treaty at the United Nations, but a close reading showed that it would ban only the stationing of weapons in space, and since neither the co-orbital Soviet ASAT nor the U.S. MHV ASAT device was to be stationed in space, the treaty would have had little impact. No negotiations were held on this text.

In March 1983, President Reagan made a nationally televised address in which he called for research into technologies that could defend the United States and its allies against ballistic missile attacks. His advisers stated that these systems could be based on the ground, or in space, leading the media to dub this the "Star Wars" speech. Concern about the militarization of space intensified following the President's address, and the initiation of testing of the U.S. MHV ASAT system.

In August 1983, the Soviets introduced a revised draft treaty at the U.N. which would ban the use of force in space, a much broader scope than the earlier draft, thereby prohibiting both ASAT and ballistic missile defense activities in orbit, although space-based BMD is already banned by the 1972 ABM Treaty.

During 1984, the potential for U.S./Soviet negotiations on space weapons dominated the headlines for many months, but it was not until 1985 that bilateral arms control talks resumed in Geneva on intermediate nuclear forces (INF) and strategic arms reduction (START). Space weapons were added as a third aspect of the discussions at that time. An INF agreement was signed by President Reagan and General Secretary Gorbachev in December 1987, while the START and space defense talks continue.

CHAPTER 6

SPACE PROGRAM MANAGEMENT AND RESOURCES

A country's ability to routinely place satellites in orbit depends on supporting resources within that country. Among the most frequently asked questions in this regard are how much the United States and Soviet Union spend on space activities, how the respective programs are managed, and how they compare with respect to launch sites and launch vehicles.

SPACE EXPENDITURES OF THE U.S. AND U.S.S.R.

The United States spent about $290 billion on the space program in the several agencies of Government involved (NASA, Departments of Defense, Energy, Commerce, Interior, and Agriculture, and the National Science Foundation) from FY59 to FY89 (current dollars unadjusted for inflation reflecting estimates for FY88 and FY89).

For the first time, the Soviet Union published space funding figures in 1989. According to the Soviets, they spend $11 billion per year on space: $6.24 billion for military space programs, $2 billion for the Energiya/Buran system, and the rest ($2.76 billion) for other non-military space activities. For years, Western experts had estimated that the Soviets spend about one and a half times as much as the United States on space, or approximately $45 billion. The large disparity between the Western estimate and the Soviet figure has left considerable doubt about what the Soviet number represents. For example, it might cover only research and development, but not procurement and operations. As a total figure for actual Soviet space funding, $11 billion is not considered credible in the West.

MANAGEMENT OF SPACE PROGRAMS

Under the terms of the National Aeronautics and Space Act (NASAct) of 1958, the United States has separate military and civilian space programs. Civilian research and development activities are under the jurisdiction of the National Aeronautics and Space Administration (NASA), while the Department of Defense (DOD) conducts military space activities. The Department of Transportation and the Department of Commerce were given substantial roles in civilian space activities during the 1970s and 1980s. Within DOD, U.S. Space Command in Colorado Springs, Colorado coordinates the operational aspects of space activities by all services; each service also has a separate Space Command. The Departments of Energy, Agriculture, Interior, and State also are involved in U.S. space programs and policy. NASA and DOD together represent more than 95 percent of the U.S. space program budget.

The National Aeronautics and Space Council, a coordinating body in the Executive Office of the President, was created in the NASAct to coordinate space policy on a Government-wide basis. It was abolished by President Nixon in 1973. President Reagan created a Senior Interagency Group/Space (SIG/Space) to coordinate U.S. space activities during his Administration, which reported to the National Security Council. Congress felt that SIG/Space was ineffective in setting space policy and, in the FY89 NASA Authorization Bill, recreated the Space Council, but without the aeronautics component. The new National Space Council, like its predecessor, is chaired by the Vice President.

The Soviet space program was operated entirely by the Strategic Rocket Forces until 1985 when a "civilian" space agency called Glavkosmos was created. The Strategic Rocket Forces are still responsible for actually launching spacecraft and almost certainly retain full responsibility for military space activities. Glavkosmos has been described by the Soviets as being responsible for building spacecraft and operating them once they are in orbit (including the Salyut and Mir space stations), as well as for commercial and international agreements. The Soviet Academy of Sciences and its institutes remain responsible for building the scientific experiments for Soviet spacecraft, and the Interkosmos Council retains responsibility over international scientific experiments, although the agreements with other countries for conducting joint space activities are now negotiated by Glavkosmos. Soviet commercial space activities have received added impetus since the creation of Glavkosmos, and currently include efforts to sell remote sensing data (see chapter 3), launch vehicles (see Introduction), opportunities to fly materials processing payloads either on free-flying spacecraft or on the Soviet space station Mir, and use of Soviet communications satellites.

LAUNCH SITES

The United States has its major launch site at Cape Canaveral, Florida (28.5°N, 80°W) for piloted, lunar, and planetary launches, and for launching satellites to geostationary orbit. It has a second launch site at Vandenberg Air Force Base, California (35°N, 121°W) for satellites which must go into polar orbits (primarily weather, remote sensing, navigation, and reconnaissance). A third minor site for small payloads is at Wallops Island, Virginia (38°N, 76°W). Short-range vertical testing is done at White Sands, New Mexico, although orbital launches are not conducted there.

The Soviet Union also has three launch sites divided into basically the same functions as those in the United States. The major site for piloted, lunar, planetary, and geostationary satellites is near Tyuratam (45.6°N, 63.4°E). The Soviets call it the Baikonur Cosmodrome, but it is about 370 kilometers from the town of Baikonur. A second, largely military site is near Plesetsk (62.8°N, 40.1°E) in the Arctic. The third site is located near Kapustin Yar (48.4°N, 45.8°E) from which launches of vertical probes (like White Sands) and small orbital payloads (like Wallops Island) are made.

Table 5 summarizes the number of launch successes from all launch sites in the world. Woomera and Hammaguir (used by the French for early launches of the Diamant booster) have been inactive for many years; Kourou, now the site of launches using the Ariane launch vehicle, also was used previously by the French for Diamant. The Indian Ocean Platform is used infrequently by Italy for launches using U.S. rockets. The other launch sites are discussed in part II of this report.

TABLE 5. World-Wide Successful Space Launches By Site

Launch Site	1989	1957-1988	Total
Plesetsk (U.S.S.R.)	45	1,202	1,247
Tyuratam (U.S.S.R.)	29	821	850
Vandenberg AFB (U.S.)	2	481	483
Cape Canaveral (U.S.)	16	378	394
Kapustin Yar (U.S.S.R.)	0	83	83
Kourou (French Guiana)	7	29	36
Tanegashima (Japan)	1	19	20
Wallops Island (U.S.)	0	19	19
Uchinoura (Japan)	1	17	18
Shuang Cheng-tzu (China)	0	17	17
Indian Ocean Platform (Kenya)	0	9	9
Xichang (China)	0	5	5
Hammaguir (Algeria)	0	4	4
Sriharikota (India)	0	3	3
Woomera (Australia)	0	2	2
Taiyuan (China)	0	1	1
Israel	0	1	1
Total	101	3,091	3,192

Prepared by CRS.

LAUNCH VEHICLES

The United States has used launch vehicles scaled to lift payloads from as light as 9 kilograms (Vanguard) up to the Saturn V which could carry over 136,000 kilograms to low Earth orbit.

The United States currently has the following families of "expendable" launch vehicle (ELVs), which can only be used once: Scout, Delta, Atlas, and Titan. The only operational reusable launch vehicle in the world is the U.S. space shuttle. Scout is the smallest of the launch vehicles and is generally used for small scientific satellites and navigation satellites (Transit). The Delta launch vehicles are used primarily for communications, weather, or navigation satellites (Navstar). Atlas launches are used primarily for geostationary communications satellites today. In the early 1960s, the Atlas was used to launch Mercury spacecraft and in the past was used for a variety of military missions. The Titan family includes a wide variety of launch capabilities. The Gemini spacecraft in the 1960s were launched with Titan IIs, which are also ballistic missiles. DOD is now reconfiguring some of the Titan IIs that are no longer needed in the ballistic missile program for use as space launch vehicles. Titan 34D and Titan IV are other current versions of the Titan, used primarily for military satellites.

The U.S. launch failures in 1986 (first the space shuttle, then a Titan and then a Delta) led to a complete reassessment of U.S. launch vehicle strategy. Originally, it had been anticipated that the space shuttle would replace Delta, Atlas and Titan and plans were underway to phase out those launch vehicles. The Air Force decided in 1984 that it wanted at least one other route to space than the shuttle, and initiated development of the Titan IV (the first was launched in 1989). Following the 1986 failures, the Government decided to adopt the Air Force philosophy of a "mixed fleet" approach in order to have assured access to space by diversifying its launch fleet. Subsequently, the Air Force contracted for a new "medium lift" vehicle, a new version of the Delta, designated Delta II. It was first launched in 1989, too. At the same time, private companies are attempting to market the Delta, Atlas and Titan launch vehicles commercially, and two entrepreneurial firms

(Space Services Inc., and AMROC) are trying to build new commercial launch vehicles. Issues involved in U.S. space launch systems are discussed in CRS Issue Brief 86121, *Space Launch Options*.

DOD and NASA are designing an Advanced Launch System (ALS) for the post-2000 time frame to launch heavy payloads into orbit for substantially less cost than current vehicles. Originally, the goal of the program was to reduce the cost per pound of payload by a factor of 10; in 1989, the Air Force conceded that a factor of 3-5 was more likely. Lack of strong mission requirements for a heavy lift vehicle, however, has complicated the ALS program and DOD has reduced its support, issuing a stop-work order on the vehicle in December 1989. Developmental work will continue on engines, an area that is primarily the responsibility of NASA.

NASA is also interested in an automated variant of the space shuttle, called Shuttle-C, in which the orbiter would be replaced by a cargo cannister. The program has not yet been approved. In addition, DOD and NASA have begun a research program to develop "aerospace plane" technologies which could ultimately be used for military and commercial aircraft and space launch vehicles (see chapter 2).

Like the United States, the Soviet Union has a variety of different launch vehicles capable of lifting different size payloads into orbit. The Soviet vehicles have several designations in the West. Some refer to them with SS numbers, others with SL numbers, and still others with NATO names. Charles Sheldon, the late Congressional Research Service specialist who originated this series of reports, developed his own alpha-numeric system which is also widely used. This system designates the vehicles with the letters A, B, C, D, F, J and K in the order in which they entered service for space launches. Upper stages are designated e, h and m. Numbers differentiate various combinations of stages. Thus, there may be D-1 launches, or D-1-e if a particular type of upper stage is added; F-1-m or F-2 vehicles, again depending on the particular configuration. Details of this designation system can be found in the *Soviet Space Program* reports prepared by CRS and published by the Senate Commerce, Science and Transportation Committee. The nomenclature system became more confused in 1986 and 1987 when the Soviets began offering their launch vehicles on a commercial basis and for the first time gave names to them. In this report, the Sheldon system will be used together with the Soviet names.

The A-1 (Vostok) and A-2 (Soyuz) vehicles have been used throughout the history of the Soviet space program for launches related to the piloted program (both for carrying crews into orbit and separate cargo flights), as well as for many other missions, particularly photographic reconnaissance satellites. In its A-2-e (Molniya) form, it is used for Molniya communications satellites and early warning satellites. The "B" launch vehicle series is no longer used. The "C" (Cosmos) is the smallest in the fleet and is used for science, navigation and minor military launches. The "D" (Proton) launch vehicle is used for space stations, geostationary satellites, the GLONASS navigation satellites, and planetary and other large science spacecraft. The "F" (Cyclone) is used for launches of ocean reconnaissance satellites and was used for the co-orbital ASAT program. It is also used for weather and remote sensing satellites. The "G" designation was used for the Saturn V-class vehicle the Soviets attempted to develop in the late 1960s for their lunar program (now known to have been designated N-1 by the Soviets).

In 1985, flights began of a new medium lift vehicle called Zenit and designated J in the Sheldon system. Zenit was launched several times in 1986-1988, but not at all in 1989. It is the launch vehicle the Cape York Space Agency would like to use for commercial launches from Australia (see Introduction).

In May 1987, the Soviets conducted a test of another new vehicle, designated K in the Sheldon system and named Energiya by the Soviets. It is similar in capability to the Saturn V. The payload did not reach orbit, however, so the test was at least a partial failure. Energiya was used to launch the Soviet space shuttle in 1988, and has not been launched since. Energiya consists of a central core, fueled by liquid hydrogen and liquid oxygen, the first Soviet launch vehicle to use this dual cyrogenic fuel combination. Four Zenit boosters are used as strap-ons (Zenit uses kerosene and liquid oxygen for fuel), and the Soviets have indicated that more strap-ons can be added if additional lift capability is required. No portion of the Energiya is reusable, although the Soviets are looking at whether or not to recover the strap-ons in the future.

Table 6 summarizes world-wide use of basic vehicles for successful launches to Earth orbit and beyond. It should be remembered that a "successful" launch simply implies that the payload reached orbit, not whether it achieved the intended orbit. In 1988, for example, a Soviet Soyuz and a Proton vehicle placed their payloads into improper orbits.

TABLE 6. World-Wide Successful Launches by Basic First Stage

Name	Country	1989	1957-1988	Total
Soyuz/Vostok/ Molniya (A)	USSR	44	1,204	1,248
Delta	USA	8	383	391
Cosmos (C)	USSR	9	354	363
Cyclone (F)	USSR	10	243	253
Atlas	USA	1	208	209
Proton (D)	USSR	11	149	160
Titan	USA	4	152	156
(B)	USSR	0	144	144
Scout	USA	0	82	82
Space Shuttle	USA	5	26	31
Ariane	ESA	7	23	30
Long March	China	0	23	23
Mu	Japan	1	16	17
N	Japan	0	15	15
Saturn V	USA	0	13	13
Saturn I	USA	0	13	13
Zenit (J)	USSR	0	11	11
Diamant	France	0	10	10
H	Japan	1	4	5
Redstone	USA	0	4	4
Jupiter	USA	0	4	4
Vanguard	USA	0	3	3
SLV-3	India	0	3	3
Lambda	Japan	0	1	1
Black Arrow	U.K.	0	1	1
Energiya (K)	USSR	0	1	1
Shavit	Israel	0	1	1
Total		101	3,091	3,192

Prepared by CRS. New analysis may alter totals for individual launch vehicles from year to year.

CHAPTER 7

FUTURE DIRECTIONS

Attempting to predict the future of the U.S. space program is a difficult assignment as it depends upon political decisions as much as on technical capabilities, both of which are virtually impossible to foretell. There are more engineering possibilities than there are financial resources likely to be made available to pursue them.

Estimating what the Soviet Union will elect to do in space is difficult, too, for all those reasons plus trying to peer through their veil of secrecy, which is thinner because of *glasnost*, but still prevents a true understanding of their program. The Soviets have stated very long-term goals (such as colonizing other planets), but have not elaborated on time frames, and the new political and budgetary climate there will complicate their planning activities.

Nevertheless, it seems useful to identify some of the possibilities facing both countries in the longer term future.

THE NATIONAL COMMISSION ON SPACE AND RIDE REPORTS

In 1986 and 1987, two reports were published relating to long-term goals for the U.S. civilian space program. The first, *Pioneering the Space Frontier*, was prepared by a specially appointed commission and looked out to the year 2035. The second, called the "Ride" report after its chief author, astronaut Sally Ride, focussed on four selected program areas through the early part of the 21st Century.

Pioneering the Space Frontier

In 1984, Congress decided that it was time to appoint an outside panel to look at the long-term future of the U.S. civilian space program. Language in NASA's FY85 authorization bill directed President Reagan to establish a National Commission on Space, with 15 members, to spend one year developing recommendations on where the space shuttle and space station programs should lead the United States. The legislation specified that the Commission take as givens both of those programs, and that military space activities not be addressed.

President Reagan officially established the Commission in October 1984, but did not name the 15 commissioners until March 1985. Chaired by former NASA Administrator Thomas O. Paine, the Commissioners spent one year assessing what the country wanted its space program to do, and making recommendations about how to satisfy those needs. Fifteen public forums were held across the United States to solicit input from citizens; monthly meetings were held at which experts could testify to the Commission on their ideas about future space programs; and letters were sent to a wide variety of well-known individuals (in and outside of the space community) in the United States asking for their input as well.

From this and their own expertise, the Commissioners developed a 50-year plan for the United States detailed in their report *Pioneering the Space Frontier*. In summary, the Commission called for the United States to lead the way in opening the inner solar system for science, exploration, and development. In doing so, the Commission envisioned establishment of bases on the Moon and Mars, and creation of a routine transportation system among the Earth, Moon and Mars. The Commissioners emphasized that they were not trying to predict the future, but rather to show what the United States could do if it so chose.

One area which the Commissioners felt was of critical importance was developing low cost access to space. They concluded that in order to achieve low cost, separate vehicles should be developed for taking people and cargo into space, unlike the space shuttle which was designed for both. For cargo transport, they recommended that the private sector be closely involved in developing the next generation launch vehicle so that it can be operated by the private sector rather than the Government. They left open the question of whether it should be derived from existing technology or completely new. For transporting people (and high value cargo) they concluded that aerospace plane technologies (see chapter 2) and advanced rocket technologies should be developed over a five year period, after which a decision could be made as to which was the better approach.

Once these vehicles are available, a "Highway to Space" would be established, permitting routine, low-cost access to Earth orbit and the Moon (using transfer vehicles from Earth orbit). The Commission envisioned people returning to the Moon by 2005 and establishing first outposts, and later settlements from which they could mine lunar resources and conduct scientific experiments (astronomers, for example, are anxious to place observatories on the far side of the Moon where they will be shielded from the interference created by humans on Earth).

To reach Mars, which the Commissioners suggested for the year 2015, a "Bridge between Worlds" would be created. The Commissioners believed that an approach different from the Apollo program should be used when sending people to Mars. Instead of going for a short time, collecting samples, and returning home, the Commissioners recommended routine access to Mars, which, like the Moon, would be a site for science, exploration, and resource development. Thus, the Commissioners envisioned two cycling spaceships on interlacing, repetitive trajectories between the Earth and Mars. Travel time to and from Mars would be approximately six months, and stay time on Mars could be as long as a year.

The report detailed a program involving both piloted and automated activities, acting synergistically to achieve the goal of opening the inner solar system. Throughout the process, the Commission envisioned the private sector following the Government and taking over operation of space facilities, for example, and making lucrative businesses out of resource operations. Although the Commission recognized that the Government would have to pave the way, it fully expected the private sector to follow. The Commission also expressed the hope that its recommendations would galvanize the most creative minds throughout the world to accomplish the goals in the report. Thus, they recommended that the United States lead the way in this area; not necessarily do it alone.

Leadership and America's Future in Space

Unlike the Commission's report, Sally Ride's *Leadership and America's Future in Space* was prepared as an internal NASA report. Dr. Ride spent approximately a year looking at four program areas for comparatively near-term (15-20 year) activities: Mission to Planet Earth, automated exploration of the solar system, a lunar outpost, and sending humans to Mars. Her report recommends that NASA pursue programs in each of these areas.

Mission to Planet Earth is the name given to a program designed to better understand Earth, the forces that act on it, how those forces interact, and what that means to the population living here. The program envisions considerable international cooperation, including satellites from many different countries, contributing to its scientific activities.

Solar system exploration would focus on three automated space science programs: the Mars rover/sample return mission designed to return samples of Martian soil; Cassini, for studying Saturn and its moon Titan; and the Comet Rendezvous/Asteroid Flyby (CRAF) mission for studying these "primitive" bodies.

The lunar outpost would involve establishing a permanent scientific facility on the Moon and to begin prospecting the Moon's resources. The Ride report envisioned humans returning to the Moon in the year 2000, preceded by automated probes to select a site for the outpost.

Concerning human exploration of Mars, Dr. Ride's group looked at what has come to be called "sprint" missions to Mars wherein crews go the planet on three quick round trips, in the same vein as the Apollo trips to the Moon. The missions, between 2005 and 2010, would each take one-year (round-trip), with crews exploring the surface for approximately two weeks. Subsequently, a commitment to a permanent Mars base could be made. She concluded that this approach was not ideal considering the scope of the activity compared with NASA's budget constraints, and that a "Mars Race" should be avoided. She concluded that "Settling Mars should be our eventual goal, but it should not be our next goal" (page 54).

As a result of the Ride report, NASA established an Office of Exploration to investigate long-range proposals for sending humans back to the Moon or to Mars. The office published a report on its progress in 1988 entitled *Beyond Earth's Boundaries*. In early 1990, the Office of Exploration was merged with NASA's Office of Aeronautics and Space Technology to form the Office of Aeronautics, Exploration and Technology. Mission to Planet Earth has now been made part of NASA's FY91 budget request (see chapter 3), and CRAF and Cassini were initiated in FY90 (see chapter 4).

PRESIDENT BUSH'S "HUMAN EXPLORATION INITIATIVE"

On July 20, 1989, the 20th anniversary of the first Apollo landing on the Moon, President Bush made a major space policy address, endorsing the goal of returning humans to the Moon and then going on to Mars "in the 21st Century." He also restated his support for the space station *Freedom* program, and for Mission to Planet Earth. Some view the President's speech as an endorsement of the National Commission on Space and Ride reports.

While the President's speech provided concrete goals for the space program, some Members of Congress criticized it for not having a specific timetable or cost estimates. The President assigned the task of developing a schedule and budget to the National Space Council. The Space Council continues to review options for meeting the President's goal of sending humans to the Moon and Mars, now named the "Human Exploration Initiative" (HEI). The HEI is controversial for several reasons. First, OMB Director Richard Darman has stated that it will cost $400 billion over 30 years. Second, there are critics who argue that human exploration of the solar system is unnecessary and too risky, preferring robotic spacecraft for such activities. A third aspect of the controversy is whether humans should return to the Moon before going to Mars, or simply proceed on to Mars since we already have been to the Moon. These issues are discussed in more detail in CRS Issue Brief 87018, *Space Policy*.

LONG-TERM SOVIET PLANS

Although few Soviet comments were made about human missions to the Moon during the 1970s and early 1980s, there have been several references in recent years to the advantages of a lunar base. Soviet scientist Vladislav

Shevchenko published an article in late 1986, for example, discoursing upon the mineral prospecting that could be done on the Moon and suggesting a scenario and time frame (2007) for creating a permanent lunar base. Late in 1987, General Vladimir Shatalov, chief of cosmonaut training, noted that it might be necessary to have crews spend up to a month on the Moon to begin readapting to gravity after a trip to Mars (although Mars itself has more gravity than the Moon, the interplanetary journey would probably be in zero-g). Once Energiya is operational, the Soviets could decide to send crews to the Moon at any time. Budgetary constraints make such a program seem unlikely in the near future, however.

It is apparent both from Soviet statements and their space station missions that Mars is their ultimate goal. They frequently state that one of the reasons they are extending the duration of piloted missions in Earth orbit is to obtain data on human reaction to spaceflight conditions so someday they can send crews to Mars. After the 237-day flight in 1984, TASS directly tied that duration to the length of time it would take to send a crew to Mars. This theme was reiterated in December 1987 at the end of the 326-day flight of Yuriy Romanenko.

There are many hurdles to overcome before crews can be sent to Mars. Although Romanenko appeared to be in very good health after his 11 months in orbit, and Titov and Manarov after their year-long stay, there is much to be understood about human reaction to long durations in weightlessness and the isolation of a spacecraft both physiologically and psychologically. For example, Romanenko admitted after eight months in orbit that he constantly felt fatigued and was not sleeping well. By the end of the mission, his work day had been cut to 4-4.5 hours.

Interplanetary flights also pose health problems not encountered in Earth orbit--particularly exposure to galactic cosmic rays, for which no effective shielding has yet been developed. Other problems will include logistical support for a crew enroute to Mars. The Soviet space station crews are frequently resupplied by cargo ships bringing food, water, equipment, repair parts, etc. Whatever supplies are needed for the Mars voyage will have to be taken with the crew (or sent on ahead). The Soviets are experimenting with techniques to create closed cycle life support systems for recycling air, water, food and waste products, but these are far from being practicable (they have had great difficulty, for example, in getting plants to go from seed, to maturity, to seed again). If closed cycle systems are not available, the logistical requirements for supporting even a small crew would be considerable.

COOPERATION BETWEEN THE UNITED STATES AND SOVIET UNION

The United States and Soviet Union have had cooperative agreements almost since the beginning of the space program, but most have been for data exchange on scientific missions. The most far-reaching agreement was signed in 1972 and provided for the Apollo-Soyuz Test Project described in chapter 2. A follow-on agreement, signed in 1977, laid the groundwork for establishment of the international satellite search and rescue system, COSPAS-SARSAT, described in chapter 3, and for cooperation on Soviet flights involving animals.

When the 1977 agreement expired in 1982, President Reagan refused to renew it because of strained relations between the two countries following the imposition of martial law in Poland. The 1983 Soviet destruction of Korean Airlines 007 further distanced the countries and space cooperation waned.

In June 1984, President Reagan invited the Soviets to participate in a joint spaceflight that would involve a simulated mission between the U.S.

space shuttle and the Soviet Salyut space station to demonstrate the ability of each side to rescue the other's space crews. At this time, however, the Soviets began linking cooperation in space with cancellation of the U.S. Strategic Defense Initiative (SDI). In the summer of 1986, however, the Soviets suddenly decoupled the two issues, and in April 1987, U.S. Secretary of State George Shultz and Soviet Foreign Minister Schevardnadze signed an agreement calling for cooperation in data exchange from planetary missions and biomedical experiments. This was expanded somewhat during the May-June 1988 summit between President Reagan and General Secretary Gorbachev.

Today, the most active discussion surrounds the potential of joint U.S./Soviet missions to Mars--first the automated rover/sample return mission described in chapter 4, and later, sending joint crews to Mars. Some supporters of a joint human mission to Mars see it as an alternative to SDI. This view was first publicly expressed by astronomer Carl Sagan at 1984 hearings by the Senate Foreign Relations Committee on a resolution introduced by Senator Matsunaga. The resolution (S. J. Res. 236) was enacted into law (P.L. 98-562), but called primarily for a resumption of the U.S./Soviet agreement for space cooperation in general, not specifically Mars.

In 1987, Congressman Robert Roe, Chairman of the House Science, Space and Technology Committee, and Congressman Manuel Lujan, ranking minority member of−29X[illegible]mittee, wrote to President Reagan asking that he raise the possibility of a joint mission with Soviet General Secretary Gorbachev at their December 1987 summit. Although President Reagan apparently did not raise the issue, Gorbachev did, at least indirectly. After signing the Intermediate Nuclear Forces (INF) treaty, Gorbachev stated that "people want to live in a world in which American and Soviet spacecraft would come together for docking and joint voyages, not for 'Star Wars.'" Dr. Roald Sagdeyev, then head of the Soviet Institute for Space Research, published an editorial in the Washington Post (December 13, 1987) in which he clarified that Gorbachev meant voyages to Mars. Although the Soviets have not formally proposed a date for sending crews to Mars, Sagdeyev allowed that his "sentimental" choice would be 2001, while conceding that 2005 would be more realistic.

Some Western observers regret the linkage between SDI and a joint Mars mission for fear that if SDI is cancelled, the Mars mission would lose impetus. Others are not sanguine about the possibility of the superpowers maintaining steady relations for a long enough period of time to complete such a mission. It might take ten years to plan and several more to carry out. There has been no period of time since World War II when U.S./Soviet relations have been stable for so long. For this reason, some supporters of missions to Mars suggest that the United States conduct the project with its allies, rather than the Soviet Union, while others suggest that it be a multi-lateral endeavor including the United States, Soviet Union, Europe, Japan and possibly other countries. The dramatic changes now occurring in the Soviet Union (and Eastern Europe) make predictions about future superpower relationships especially difficult.

There is also the potential problem of technology transfer. If the two countries are to the mount the entire mission jointly, it would be virtually impossible not to share technology. One possible solution would be for the countries to have coordinated missions that go at the same time, but on different spacecraft. Another solution is simply to accept that technology transfer will occur. The attractiveness of the latter option will be dependent on how the superpowers view each other at the time joint human missions to Mars are actually being designed, which, as noted, is virtually impossible to forecast today.

CHAPTER 8

TABLE OF SPACE "FIRSTS"–U.S. AND SOVIET

Any attempt to compare the relative pace of the two principal space programs through a table of "firsts" has certain weaknesses, as it does not answer by how many days or years a particular event occurred in one country before another. Further, it does not distinguish between a nominal first accomplishment in crude form by one country, sometimes followed by a much more impressive and elaborate follow-up by the other country. Nonetheless, such firsts do affect public opinion, and analysis by various fields of endeavor may give some sense of relative direction of pacing efforts in each country. Table 7 attempts such a measure.

TABLE 7. Major U.S. and Soviet Space "Firsts"

United States

Event	Satellite	Launch Date
Biological and Piloted Flight		
Piloted orbital maneuver	Gemini 3	03/23/65
Controlled extravehicular activity	Gemini 4	06/03/65
Piloted space rendezvous	Gemini 6, 7	12/04/65
Piloted docking with automated vehicle	Gemini 8-Agena	03/16/66
Piloted lunar orbit	Apollo 8	12/21/68
Piloted lunar return reentry	Apollo 8	12/21/68
Lunar orbit rendezvous	Apollo 10	05/18/69
Lunar landing and return	Apollo 11	07/16/69
Piloted lunar rover	Apollo 15	07/26/71
International docking	Apollo	07/15/75
Flight of reusable vehicle	STS 1	04/12/81
4-person crew	STS 5	11/11/82
5-person crew	STS 7	06/18/83
6-person crew	STS 9	11/28/83
Untethered EVA	STS 41-B	02/03/84
In-orbit satellite repair	STS 41-C	04/06/84
7-person crew	STS 41-G	10/05/84
Satellite retrieval/return	STS 51-A	11/08/84
8-person crew	STS 61-A	10/30/85
Science*		
Van Allen radiation belts	Explorer 1	02/01/58
Earth shape measured	Vanguard 1	03/17/58
Orbiting solar observatory	OSO 1	03/07/62
Data from Venus	Mariner 2	08/27/62
Geodetic satellite	Anna 1B	10/31/62
Lunar close-up pictures	Ranger 7	07/28/64
Mars pictures	Mariner 4	11/28/64
Micrometeorite satellite	Pegasus 1	02/16/65
Lunar orbit pictures	Orbiter 1	08/10/65
Lunar trenching	Surveyor 3	04/17/67
Lunar soil chemical analysis	Surveyor 5	09/08/67
Live lunar TV broadcast	Apollo 8	12/21/68
Return of lunar rocks	Apollo 11	07/16/69
Color pictures of Jupiter	Pioneer 10	03/03/72
Color pictures of Saturn	Pioneer 11	04/06/73
Radiotelescope in lunar orbit	Explorer 49	06/10/73
Pictures of Venus	Mariner 10	11/03/73
Pictures of Mercury	Mariner 10	11/03/73
Solar Probe	Helios 1	12/10/74
Mars surface pictures	Viking 1	08/22/75
High energy astronomy observatory	HEAO 1	08/12/77
Pictures of Jupiter and its Moons	Voyager 1	09/05/77
Pictures of Saturn and its Moons	Voyager 1	09/05/77
Pictures of Uranus and its Moons	Voyager 2	08/20/77
Pictures of Neptune and its Moons	Voyager 2	08/20/77
Comet intercept (Giacobini-Zinner)	ICE	08/12/78

TABLE 7. Major U.S. and Soviet Space "Firsts"--continued

Union of Soviet Socialist Republics

Event	Satellite	Launch Date
Biological and Piloted Flight		
Animal in space (dog)	Sputnik 2	11/03/57
Animal in space, recovered	Korabl Sputnik 2	08/19/60
Man in space, recovered	Vostok 1	04/12/61
Woman in Space, recovered	Vostok 6	06/16/63
Multi-crew spacecraft	Voskhod 1	10/12/64
Extravehicular activity	Voskhod 2	03/18/65
Recovery, circumlunar live animals	Zond 5	09/21/68
Docking between piloted spacecraft	Soyuz 4/5	01/14/69
Space station	Salyut 1	04/19/71
International docking	Soyuz 19	07/15/75
2 ferry craft docked to station	Soyuz 26/27	01/10/78
International crew launch	Soyuz 28	03/02/78
Construction in space	Soyuz T-9	06/27/83
Woman EVA	Soyuz T-12	07/17/84
Crew Rotation	Soyuz T-13/T-14	09/00/85
Ferry between space stations	Soyuz T-15	03/13/86
Science*		
Orbiting geophysical lab	Sputnik 3	05/15/58
Farside lunar picture	Luna 3	10/04/59
Cosmic ray measurements	Proton 1	07/16/65
Pictures from lunar surface	Luna 9	01/31/66
Lunar surface bearing test	Luna 13	12/21/66
Venus atmospheric probe	Venera 4	06/12/67
Automated return of lunar sample	Luna 16	09/12/70
Automated lunar roving laboratory	Luna 17	11/10/70
Venus soil analysis	Venera 8	03/27/72
Venus surface pictures	Venera 9	06/08/75
Radio telescope 10-meter dish	Salyut 6	09/29/77

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*This table shows launch dates rather than the date of the event described. This is particularly important to remember with the science missions, since the event may occur years after launch. For example, Voyager 2 was launched in 1977, but encountered Uranus in 1986 and Neptune in 1989.

TABLE 7. Major U.S. and Soviet Space "Firsts"--continued

United States		
Event	Satellite	Launch Date
Civil and Military Applications		
Active communications	Score	12/18/58
TV pictures from space	Explorer 6	08/07/59
Weather satellite	Tiros 1	04/01/60
Navigation satellite	Transit 1B	04/13/60
Missile detection	Midas 2	05/24/60
Observation recoverable flight	Discoverer 13	08/10/60
Passive communications	Echo 1	08/12/60
Operational synchronous communications	Syncom II	07/26/63
Nuclear explosion detection	Vela Hotel	10/17/63
Earth resources satellite	ERTS 1	07/23/72
Synchronous 24-hour weather	SMS 1	05/17/74
Commercial maritime communications	Marisat 1	02/19/76
Ocean resources satellite	SeaSat 1	06/27/78
Space Flight and Propulsion		
Multiple spacecraft payload	Transit/Solrad	06/22/60
Payload recovery	Discoverer 13	08/10/60
Hydrogen rocket orbited	Centaur 2	11/27/63
Docked spacecraft maneuver	Gemini 10-Agenda	07/18/66
Lunar-velocity reentry	Apollo 4	11/09/67
Constant deceleration reentry	Apollo 8	12/21/68
Mars orbit	Mariner 9	05/30/71
Jupiter flyby	Pioneer 10	03/03/72
Solar system escape	Pioneer 10	03/03/72
Venus/Mercury flyby	Pioneer 10	03/03/72
Jupiter/Saturn flyby	Pioneer 11	04/05/73
Uranus/Neptune flyby	Voyager 2	08/20/77
Libration point halo orbit	ISEE 3	08/12/78
Auxiliary Power Systems		
Solar cells	Vanguard 1	03/17/58
Isotope power	Transit 4A	06/29/61
Nuclear reactor in orbit	Snapshot 1	04/03/65
Fuel cell	Gemini 5	08/21/65

TABLE 7. Major U.S. and Soviet Space "Firsts"--continued

Union of Soviet Socialist Republics

Event	Satellite	Launch Date
Civil and Military Applications		
Domestic communications	Molniya 1-1	04/23/65
Fractional orbit bombardment	Cosmos 139	01/25/67
Co-orbital antisatellite test	Cosmos 248-249	10/20/68
Radar ocean surveillance	Cosmos 626?	12/29/73
Space Flight and Propulsion		
Space flight	Sputnik 1	10/04/57
Earth escape spacecraft	Luna 1	01/02/59
Lunar impact	Luna 2	09/12/59
Orbital platform launch	Sputnik 5	02/21/61
Venus flyby	Venera 1	01/12/61
Mars flyby	Mars 1	11/02/62
Venus impact	Venera 3	11/16/65
Lunar soft landing	Luna 9	01/31/66
Lunar orbiter	Luna 10	03/31/66
Automatic docking	Cosmos 186/188	10/27-29/67
Recovery, lunar payload	Zond 5	09/21/68
Skip reentry lunar payload	Zond 6	11/10/68
Venus soft landing	Venera 7	07/17/70
Mars impact	Mars 2	05/19/71
Mars soft landing	Mars 3	05/28/71
Venus orbit	Venera 9	06/18/75
Automatic propellant transfer	Progress 1	01/20/78
Auxiliary Power Systems		
Battery power	Sputnik 1	10/04/57
Gallium arsenide solar panel addition	Salyut 7	04/19/82

Prepared by CRS.

PART TWO

SPACE ACTIVITIES OF OTHER LAUNCHING COUNTRIES/ORGANIZATIONS

For the first two decades of the space program, the United States and Soviet Union clearly dominated space activities. While they still are responsible for the vast majority of space launches today, the 1980s witnessed the emergence of five additional launching countries/organizations: China, the European Space Agency (a group of 13 European nations), India, Israel, and Japan.

Four other countries--Australia, France, Italy, and the United Kingdom--are sometimes counted as launcher countries, but are not included here. Australia and Italy have both operated launch facilities. Australia launched its own satellite, Wresat, from Woomera in 1967. Since a U.S. rocket was used for the launch and no other Australian launches have been made, it is not counted here as a launcher country. Italy's facility (the San Marco Platform off the coast of Kenya) is still used occasionally, and Italy has launched five of its own satellites, but these also have used U.S. launch vehicles, so Italy is not counted as a launching country.

France and the United Kingdom did develop their own launch vehicles. The French Diamant successfully placed 12 payloads in orbit from 1965 to 1975, but was then phased out of service. At first, the French launched from Hammaguir, Algeria. In 1970, they transferred operations to the Kourou facility in South America. The British Black Arrow successfully placed one satellite (Prospero) in orbit in 1971 from Woomera, Australia, but the rocket was never used again for space launches. Since their indigenous launch vehicles are no longer in use, neither country is included here as a separate launching country, although both are now members of the European Space Agency (ESA).

In 1989, Iraq launched a missile that reportedly placed some material in orbit for a short time. Iraq announced that it was developing a space launcher, but this flight is generally considered to have been a test of an ICBM (intercontinental ballistic missile). Although many space launch vehicles have developed from ICBMs in both the United States and Soviet Union, at this point, the Iraqi flight seems more related to a military missile objective, so Iraq is not included here as a space launching country. If it develops a satellite and launches it into orbit, Iraq will be added.

CHAPTER 1

CHINA

China launched its first satellite in 1970. By the end of 1989, it had made a total of 23 launches, successfully placing 24 satellites into orbit (there were no Chinese launches in 1989). Several of these have been recovered and some may be related to development of a reconnaissance satellite capability (recovery is necessary for film-type reconnaissance satellites). Several others were not recovered and their missions remain unclear. They could have had scientific missions or could have been related to a different type of reconnaissance capability (electronic intelligence, for example). One launch in 1981 which placed three spacecraft into orbit simultaneously, and one of the 1987 launches, were for science. Others have been for communications. One of the more interesting launches was China 20 in 1987; it was China's first commercial launch, taking a materials processing experiment into space for the French company Matra. A similar flight was made in 1988 for a German consortium, Intospace.

Most Chinese launches take place from Shuang Cheng-tzu (41.2°N, 100.1°E) in the northern part of China (near Jiuquan). The Long March 2 rocket is used at this site. In 1984, the Chinese introduced the Long March 3 (CZ 3) launch vehicle, which has a cryogenic (liquid oxygen/liquid hydrogen) upper stage. The vehicle inaugurated use of a new launch site at Xichang (28°N, 103°E) in southeastern China. The first launch of the Long March 3 did not put the payload in the correct orbit and is counted in this report as a launch success, but a payload failure. Several more successful launches of the Long March 3 have followed, placing Chinese communications satellites in geostationary orbit. In 1988, the Chinese launched their first weather satellite using a new version of their rocket, Long March 4, and a new launch site, Taiyuan (38°N, 112°E). The satellite was placed into a polar orbit and apparently failed soon after launch. Another weather satellite is planned for 1990.

The Chinese are now actively marketing the Long March 2 and 3 abroad. The 1987 French and the 1988 German experiments were launched on the Long March 2. For the past several years, there have been reports about American companies signing contracts to launch satellites on Chinese boosters, and it has been extremely difficult to determine how many agreements were actually signed. In 1988, the first export license requests were made to the U.S. State Department to send U.S. satellites to China for launch. The requests were for two Australian satellites, Aussat 1 and 2, being built by Hughes Aircraft, and one satellite named Asiasat-1, which is the refurbished Westar 6 satellite (also built by Hughes) recovered by a space shuttle crew in 1984 after it failed to achieve the proper orbit. Asiasat Inc., which bought Asiasat-1, is a company owned by three entities, each having a one-third share: Cable and Wireless PLC of London, Hutchinson Telecommunications Ltd. of Hong Kong, and CITIC Technology Inc., a subsidiary of China's International Trust and Investment Corp. Cable and Wireless has overall management responsibility for Asiasat; the company is based in Hong Kong.

In September 1988, the Reagan Administration conditionally approved export of the three satellites to China. The conditions were that China sign three international treaties concerning, among other things, liability for damage from space launches; that China negotiate a fair trade agreement with the United States regarding launch services; and that agreement be reached on protecting technology while each satellite is in China. All these conditions were met by January 1989. One of the conditions to which China agreed was that it would seek to launch no more than 9 international satellites between 1989 and 1994. Approval for the export of the Aussat and Asiasat satellites was granted by CoCom, the Coordinating Committee on Multilateral Export Controls, whose members are all the NATO countries (except Iceland) and Japan. Following the Tiananmen Square uprising in June 1989, however, the

Bush Administration suspended all export licenses for items on the Munitions Control List, including the three satellites. Congress passed legislation prohibiting the export of the satellites unless conditions improved in China, or unless the President certified to Congress that it was in the national interest of the United States to reinstate the licenses. In December 1989, the President made that certification to Congress. Asiasat is now scheduled for launch in April 1990. The Ausat satellites are still under construction in California. The Administration has emphasized that export license decisions will be made on a case by case basis, so it is not clear when or if other satellites will be exported to China for launch.

The Chinese have expressed an interest in weather and land remote sensing satellites. They inaugurated use of a Landsat receiving station purchased from the United States in 1986, which may also be able to receive data from the French SPOT satellite. As noted, they launched their first weather satellite in 1988 and plan another in 1990 (the first apparently failed soon after launch).

In 1984, China signed three agreements for cooperation in space technology with the Federal Republic of Germany, Italy, and France, and discussions have been held with Brazil. Regarding U.S./Chinese cooperation, the Chinese have indicated that they would like to fly an astronaut on the space shuttle, and in 1986 selected two student experiments for the shuttle.

The history of the Chinese space program is still shrouded in secrecy, but occassionally information is released. For example, the Chinese announced in 1984 that they had flown a puppy into space on a suborbital rocket in 1967. The puppy, named Xiao Bao (Little Leopard), was successfully recovered. They also reported that there had been a major explosion at one of their launch pads on January 28, 1978, which resulted in at least seven people being seriously injured, and a dozen or more people receiving burns to their hair, eyebrows, and faces. In addition, they honored as a martyr a young engineer who helped develop the first geostationary satellite, but died after 6 or 7 years of suffering the health effects of exposure to radiation during experiments related to that task.

It is extremely difficult to discuss the future of the Chinese space program, not only because they do not release very much information about their activities, but also because their plans change quite abruptly. During 1979 and 1980, they expressed great plans for utilization of space, and even had astronauts in training. In late 1980 and early 1981, however, they retreated from their expansive plans because of a reassessment of the Chinese economic situation, and announced that their piloted space program had been postponed for at least the remainder of the decade. Today, they talk boldly about building space stations and a space shuttle, although it does not seem likely that they would do so before the year 2000. There are reports that they once again are training astronauts. The current political situation in China further complicates assessing the future of the Chinese space program.

TABLE 8. Chinese Space Launches

Name	Launch Date	Launch Site	Comments
China 1	04/24/70	S	Engineering test. "East is Red" song played until 05/20/70.
China 2	03/03/71	S	Housekeeping test and possible science.
China 3	07/26/75	S	Science? Reconnaissance? Not recovered.
China 4	11/26/75	S	Possible reconnaissance test. Recovered.
China 5	12/16/75	S	Like China 3.
China 6	08/30/76	S	Possible electronics intelligence gathering test and/or science. Not recovered.
China 7	12/07/76	S	Possible reconnaissance test. Recovered.
China 8	01/26/78	S	Possible reconnaissance test. Recovered.
China 9-11	09/19/81	S	Triple scientific payload for space physics experiments.
China 12	09/09/82	S	Possible reconnaissance test. Recovered.
China 14	01/29/84	X	First Long March 3 launch; upper stage failed.
China 15	04/08/84	X	First Chinese geostationary communications satellite.
China 16	09/12/84	S	Possible reconnaissance. Recovered.
China 17	10/20/85	S	Possible reconnaissance. Recovered.
China 18	02/01/86	X	Communications.
China 19	10/06/86	S	Possible reconnaissance. Recovered.
China 20	08/05/87	S	Materials processing experiment for a French company.
China 21	09/09/87	S	Science. Recovered.
China 22	03/07/88	X	Communications
China 23	08/05/88	S	Materials processing for German company.
China 24	09/06/88	T	Weather
China 25	12/22/88	X	Communications.

S = Shuang Cheng-tzu. X = Xichang. T = Taiyuan. Launch dates are in Greenwich Mean Time.

Prepared by CRS based on data from Chinese news bulletins; *World-Wide Space Activities* (House Science and Technology Committee, 1977); and Clark, P. S. The Chinese Space Programme. *Journal of the British Interplanetary Society*, v. 37, 1984. p. 195-206.

CHAPTER 2

EUROPEAN SPACE AGENCY AND ARIANESPACE

The European Space Agency (ESA) was formed in 1975 by the merger of the European Scientific Research Organization and the European Launcher Development Organization. It has thirteen members (Austria, Belgium, Denmark, France, Federal Republic of Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom), and a technical agreement of cooperation with Canada as well.

A major ESA activity has been development of an independent launch capability using a launch vehicle called Ariane. France played the lead role in developing Ariane, and the vehicle is launched from Kourou (5.2°N, 52°W) in French Guiana (South America). In addition, Arianespace, a private company which now markets Ariane and manages the launches, is incorporated in France. As a result, Ariane is often mistakenly referred to as a French launch vehicle.

Arianespace, as noted above, is now responsible for operational Ariane launches so it, rather than ESA, is the "launching organization" included here. ESA continues to upgrade Ariane performance, and is responsible for test launches. Its activities will continue to be included in this report. Several ESA members (notably France, Italy and West Germany) have their own strong indigenous space programs, but the nature of this report does not permit extensive discussion of them.

Although the world's attention in 1986 was focussed on U.S. launch failures, Ariane had its own problems. After two successful launches, it failed in May and did not resume service until September 1987, several months later than originally expected. In February 1990, another Ariane exploded and future launches have been delayed indefinitely. Arianespace is still the world leader in attracting customers, although they will experience greater competition now that commercial companies in the United States are offering their own vehicles (the Delta, Atlas, and Titan) on the market. China and the Soviet Union, as already noted, are also competing.

ESA will continue to develop advanced versions of Ariane, and is currently developing the Ariane 5 which, in addition to being capable of placing 15,000 kilograms into low Earth orbit or 4,500 kilograms into geostationary orbit, would be reusable. France proposed development of a small reusable piloted vehicle called Hermes which could be launched on an Ariane 5, and ESA approved development of Hermes in 1986. Ariane 5, Hermes, and Columbus (their contribution to the U.S.-led space station) are the three major programs currently underway in ESA. It does, however, have a variety of other programs for space science and applications. (These programs are all civilian; ESA is prohibited by its charter from conducting military space programs.)

For example, ESA launched a spacecraft, called Giotto, to Halley's Comet in 1985. The probe was the only one of the five Halley's Comet probes to enter the nucleus of the comet, and it returned excellent data that is still being analyzed. ESA's Earth-orbiting astronomical observatory, Hipparchos, was launched in 1989, although it was placed into an improper orbit because of an upper stage malfunction. Scientists are receiving usable data from it, however. Other approved programs included the ERS remote sensing satellite, and ROSAT (an x-ray observatory). ESA operates geostationary weather satellites (Meteosat) and developed communications satellites, too.

ESA's programs have involved a considerable degree of cooperation with the United States. This cooperation has resulted in some discord, however, because of budget constraints within NASA which led to cancellation of the U.S. half of a joint project called the International Solar Polar Mission

(ISPM). Originally, ISPM would have involved the launch of two probes to simultaneously study the North and South poles of the Sun. ESA and NASA would each have provided one spacecraft, and NASA would have supplied the power unit (a radioisotope thermal generator), launch, and tracking for both probes. In 1981, the United States unilaterally abrogated the memorandum of understanding with ESA on ISPM, prompting formal statements of displeasure from several ESA member countries to the U.S. State Department. Nevertheless, the mission could not be accommodated within NASA's budget, and the U.S. spacecraft was cancelled. NASA has kept its commitment to provide the power unit, launch, and tracking for the ESA spacecraft, which has been renamed Ulysses and is now scheduled for launch in the fall of 1990.

Relations between NASA and ESA cooled slightly because of the ISPM incident, but the two agencies continue to develop programs jointly. For example, ESA has agreed to participate in NASA's space station program, building on its experience with Spacelab, a scientific laboratory which is carried inside the cargo bay of the space shuttle, thereby providing a "shirt-sleeve" environment for performing a wide variety of experiments.

Spacelab was developed as a cooperative project with NASA during the 1970s. Spacelab pallets have also been developed by ESA for use outside the habitable module for those experiments which require exposure to the space environment. The first Spacelab module was turned over to NASA in December 1981, and was launched in November 1983. The crew included an ESA astronaut, Ulf Merbold of West Germany, the first non-American to fly on an American piloted mission. West Germany was the lead country in Spacelab development and, along with Italy, proposed using Spacelab modules to form a European space station. Called Columbus, the concept served as the basis for plans to provide a habitable module as part of the NASA/international space station. ESA is also developing a free-flying platform called Eureca (European Retrievable Carrier) as a follow-on to the Spacelab pallet. Eureca platforms will serve as a structure (or "bus") for providing power supply and orbit stabilization systems for payloads which can be placed on and later removed from it. The platform will be deployed from and retrieved by the U.S. space shuttle, and can accommodate 1000 kilograms of payload.

TABLE 9. European Space Agency/Arianespace Launches

Name	Launch Date	Comments
CAT	12/23/79	Success. First test launch. Carried CAT test package.
Firewheel; Oscar 9	05/23/80	Failure. Second test launch. One scientific and one communications satellite lost.
Meteosat; Apple	06/19/81	Success. Third test launch. Launched European weather satellite and experimental Indian satellite.
Marecs	12/20/81	Success. Fourth and final test launch.
Marecs B; Sirio 2	09/09/82	Failure. First operational launch. Two communications satellites lost.
ECS; Oscar 10	06/16/83	Success. Placed two communications satellites in orbit.
Intelsat	10/19/83	Success. Communications satellite.
Intelsat	03/05/84	Success. Communications satellite.
GTE Spacenet	05/22/84	Success. Communications satellite. First launch operations by Arianespace.
ECS-2; Telecom 1A	08/04/84	Success. Two communications satellites.
GTE Spacenet Marecs B2	11/09/84	Success. Two communications satellites.
Arabsat; Brazilsat	02/08/85	Success. Two communications satellites.
GSTAR-1; Telecom 1B	05/08/85	Success. Two communications satellites.
Giotto	07/02/85	Success. Halley's Comet probe.
GTE Spacenet ECS 3	08/12/85	Failure. Two communications satellites lost.
SPOT; Viking	02/22/86	Success. French remote sensing satellite and Swedish scientific satellite.
GSTAR III; Brazilsat	03/28/86	Success. Two communications satellites.
Intelsat	05/30/86	Failure. One communications satellite lost.
AUSSAT; ECS-4	09/15/87	Success. Two communications satellites.
TVSAT 1	11/21/87	Success. Communications satellite.
GTE Spacenet; Telecom 1C	03/11/88	Success. Two communications satellites.
Intelsat	05/17/88	Success. Communications.
Meteosat; Amsat;	06/15/88	Success. First launch of Ariane 4. Weather, amateur radio, and communications satellites. Panamsat
Insat 1C; ECS-5	07/21/88	Success. Two communications satellites.
Gstar 3; SBS 5	09/08/83	Success, but Gstar kick motor failed. SBS communications satellite OK.
TDF 1	10/20/88	Success. Communications.
Skynet 4B; ASTRA 1B	12/11/88	Success. Two communications satellites.
Intelsat	01/26/89	Success. Communications satellite.
JCSAT; MOP	03/06/89	Success. JCSAT is Japanese communications satellite; MOP is European weather satellite.
Tele-X	04/01/89	Success. Swedish communications satellite.
Superbird; Kopernikus	06/05/89	Success. Superbird is Japanese communications satellite; Kopernikus is German communications satellite.
Olympus	07/11/89	Success. European communications satellite.
TV-SAT; Hipparchos	08/09/89	Success. TV-SAT is German communications satellite; Hipparchos is European astronomical satellite that was placed into an improper, but usable, orbit.
Intelsat	10/27/89	Success. Communications satellite.

All launches are from Kourou, French Guiana (South America). Does not include launches conducted for Europe by other countries. Prepared by CRS.

CHAPTER 3

INDIA

India has been involved in developing satellites and launch vehicles for many years. Its first satellite, Aryabhata, was launched by the Soviet Union in 1975. While cooperation with the Soviets has continued (they launched three remote sensing satellites for the Indians--Bhaskara 1 and 2 in 1979 and 1981 respectively, and IRS in 1988), and there is extensive cooperation with the West as well, India has pursued development of an independent launching capability. The Indian Space Research Organization (ISRO) is the primary Government space agency in India, and is based in Bangalore. Launches are made from Sriharikota (in the Bay of Bengal, 13°N, 80°E).

The first test launch of the Indian booster SLV-3 failed in August 1979. The Indians achieved success with their second test launch on July 18, 1980, however, which placed the Indian satellite Rohini 1 into Earth orbit (it remained in orbit until July 1981, longer than expected). The third SLV-3 flight took place on May 31, 1981, and although it succeeded in placing Rohini 2 into orbit, the altitude was lower than planned and the satellite decayed after only 9 days (instead of the expected 300 days). These Rohini satellites are primarily for monitoring the performance of the launch vehicle, although Rohini 2 also carried remote sensing equipment. On April 17, 1983, the Indians orbited Rohini 3 and announced it was for Earth resources studies. Some Western sources have suggested that the Indians are attempting to develop a military reconnaissance capability. In March 1987, they tested a new Augmented Satellite Launch Vehicle (ASLV). The test flight failed, as did a second test in July 1988.

The Indians developed an experimental communications satellite, APPLE, which was launched on the third Ariane test flight in June 1981. One of the solar panels did not deploy properly, but the satellite operated with reduced power for two years. In April 1982, the United States launched INSAT 1A for the Indians. The satellite had three functions: meteorology, voice and data transmissions, and direct broadcast transmissions. Several problems developed with the satellite once it was in orbit (the solar sail did not deploy at all, and the C-band antenna would not deploy for several weeks), and by September its fuel supply (which should have lasted for many years) was exhausted, apparently because an open valve allowed the fuel to escape. The back-up satellite, INSAT 1B, was launched by the space shuttle in 1983 and is operating correctly. INSAT IC was launched by an Ariane in 1988, and another INSAT was scheduled for launch on a U.S. Delta II rocket in 1989, but was damaged during an accident on the launch pad during launch preparations. It was returned to the manufacturer for repairs.

The INSAT program developed partially out of a cooperative program with the United States called SITE. From 1975 to 1976, the United States lent its ATS-6 satellite to India for use in transmitting educational programs to 5,000 remote Indian villages. The Indian government developed the programming itself and the project was considered such a success that the direct broadcast part of the INSAT series was created to carry on.

India is far from having its own ability to place people in space, but there has been an Indian cosmonaut. In April 1984, an Indian military pilot, Rakesh Sharma, flew into space on Soyuz T-11 with two Soviet cosmonauts and docked with the Salyut 7 space station, which was already occupied by three other cosmonauts. Sharma remained on board the space station for seven days, participating in a variety of experiments including performing yoga to determine if special muscle relaxation techniques would help overcome the temporary physiological effects of weightlessness. The Indians also hope to send a scientist into space on a U.S. space shuttle mission.

TABLE 10. Indian Space Launches

Name	Launch Date	Comments
SLV 3	08/10/79	**Test flight. Failure.**
Rohini 1	07/18/80	**Test satellite. Success.**
Rohini 2	05/31/81	**Test satellite. Lower orbit than planned, but satellite worked for 9 days.**
Rohini 3	04/17/83	**Remote sensing. Success.**
ASLV	03/24/87	**Test flight of new vehicle. Failure.**
ASLV	07/13/88	Failure.

Does not include launches conducted for India by other countries. Prepared by CRS.

CHAPTER 4

ISRAEL

On September 19, 1988, Israel became the newest member of the family of launching countries, placing its first satellite, Horizon 1 (Offeq 1) into orbit. To avoid flying over other countries during launch, the Israelis used a highly unusual flight path which headed northwest over the Mediterranean. This trajectory placed the satellite into a retrograde orbit (against the direction of the Earth's rotation), at an inclination of 143°. The satellite was not designed to operate for very long, and it reentered Earth's atmosphere in January 1989.

The 156 kilogram satellite was a test spacecraft. Observers speculate that it was the first step in the development of a reconnaissance satellite. U.S. and Soviet reconnaissance satellites are placed into polar orbits which allow the satellite to view any place on the globe. If the Israelis continue to use the type of flight path they did on their first launch, the satellite's view will be limited to areas 37 degrees north and south of the equator. This would give them good coverage of their Middle East neighbors, but not of the Soviet Union, for example.

The Israelis did not announce the location of the launch site. Analysis by the Kettering Group places it near Ashdod, on the coast south of Tel Aviv, with the approximate coordinates 31.9°N, 34.7°E. Other Western observers say the site is in the Negev Desert. The Israelis stated that the launch vehicle was named Shavit, and Western observers speculate that it is based on the Jericho II missile. The Israelis said they would launch another satellite in 1989, but did not. Their current plans are unknown, but in 1988 they also announced that a third, more advanced, satellite would be launched in 1992.

CHAPTER 5

JAPAN

Over the past several years, Japan has released space program plans for the future which involve a very ambitious level of activity, including launching astronauts on the U.S. space shuttle, participating in the U.S./International Space Station *Freedom* program, and developing its own piloted program. To date, however, the Japanese space program has focused on development of launch vehicles, and communications, weather, and scientific satellites. There are two organizations involved in launching satellites in Japan: the National Space Development Agency (NASDA), and the Institute of Space and Astronomical Science (ISAS).

Japan uses a mixture of U.S. and Japanese technology in its space activities. Some Japanese satellites have been purchased from U.S. aerospace companies, while others were built by Japanese firms subcontracting with U.S. companies. During the early years of the program, some orbital launches were provided by the United States, but NASDA later relied on the "N" launch vehicle, manufactured in Japan under license from the McDonnell-Douglas Corporation (it is based on McDonnell Douglas' Delta launch vehicle). A smaller rocket, called the Mu, is the one used by ISAS for scientific satellites. The ISAS launch facility is on the island of Uchinoura (32°N, 130°E) 900 kilometers southwest of Tokyo. NASDA launches from Tanegashima (31°N, 130°E), an island south of Uchinoura.

Like Arianespace, Japan is likely to offer stiff economic competition to the United States, but not in terms of providing launch services, at least in the near term. Rather, Japan seems likely to compete in the area of space technology itself, particularly communications satellites and associated ground stations. For example, in 1977, the Japanese launched the first experimental communications satellite to operate at the frequencies of 30/20 Gigahertz. Most communications satellites today operate at lower frequencies, and those bands are becoming congested; 30/20 GHz technology is expected to be the wave of the future. In the United States, policy disputes over whether the Government or private industry should pay for developing advanced communication satellite technology slowed development of U.S. technology, while the Japanese forged ahead. Their first operational 30/20 GHz satellite, CS 2, was launched in February 1983.

Communications satellites have become a highly controversial area in trade relations between the U.S. and Japan. In 1989, the U.S. Trade Representative (USTR) filed a "Super 301" trade action against Japan because of alleged unfair trading practices in three areas, one of which was communications satellites. The USTR complaint is that Japan has prohibited procurement of communications satellites from foreign sources if the satellite is for use by the Japanese government or its quasi-private telecommunications agency, NTT. The Japanese assert that they have not closed their market to American firms. This issue was not resolved at the end of 1989.

In 1981, the Japanese successfully launched the first improved version of the "N" launch vehicle, "N II," which can place 350 kilograms in geostationary orbit. They also announced plans to develop an H-1 vehicle which can place 550 kilograms in geostationary orbit, and uses liquid hydrogen/liquid oxygen fuel. The first test launch of the H-1 was successfully conducted in 1986, and it is now operational and has replaced the N II. The 1969 agreement with the United States, which allows access to launch vehicle technology, prohibits Japan from transferring that technology to third countries and from launching satellites for third countries without prior agreement from the United States. Because of this latter provision, Japan is not seen as a near-term launch competitor to the United States. Japan is planning to develop the H-2 launch vehicle, which will be more capable than the H-1 (two tons to geostationary orbit) and will be built entirely by Japan.

This will relieve them of the restrictions placed on them by the 1969 agreement with the United States. The Japanese are limited by government agreements with fisherman near the two launch sites to launch no more than twice per year out of each site, limiting the total number of annual launches Japan can make. Japan has shown some interest in offering commercial launch services once the H-2 is operational, but would probably have to renegotiate with the fishermen, or build another launch site elsewhere in the Pacific, perhaps in conjunction with other interested parties. One possibility is using the Cape York, Australia launch site being proposed by the Cape York Space Agency (see Introduction). The H-2 development program suffered a setback in 1989, with the expected launch date for the first vehicle delayed by a year to 1993.

Japan is participating with NASA in the development of the space station *Freedom*, and has chosen Mitsubishi Heavy Industries as prime contractor for building one of the four space station modules. Part of the module will be pressurized, while another section will be open to the space environment. Japan has agreed to spend $1 billion over 10 years in support of the space station program. The Japanese government has selected three astronauts, one of whom will fly on the U.S. space shuttle during a mission dedicated to Japanese materials processing experiments. Separately, a Japanese journalist is being selected to fly to the Soviet space station Mir.

The Japanese expressed interest in constructing a "mini-shuttle," smaller than the U.S. space shuttle, but with most of the shuttle's basic features, including reusability, and the ability to carry a crew of four. Today, however, they are focussing on plans to develop an automated vehicle, HOPE, that would be launched by the H-2 and not carry any crew. They also have initiated planning for an aerospace plane designated HIMES which would be similar to the U.S. NASP (see chapter 2).

Japan has space programs for applications and space science, as well. In addition to geostationary weather satellites (the GMS series), in 1987, the Japanese launched the Marine Observation Satellite (also called MOMO) to study ocean surface temperatures. A second was launched in February 1990. The JERS land remote sensing satellite is scheduled for launch in 1990 (originally a 1986 launch date had been proposed) and will help explore for oil and mineral resources. Plans call for the satellite to carry a synthetic aperture radar, a stereo camera, and visible and infrared radiation measurement systems. In 1995, Japan plans to launch ADEOS, the Advanced Earth Observing System, which will carry two NASA instruments along with others. JERS and ADEOS will provide data relevent to Mission to Planet Earth (see chapter 3).

As already noted, Japan sent two probes to the vicinity of Halley's Comet in 1986. In January 1990, the Japanese launched their first probe to the Moon, called Muses-A. It is primarily an engineering test rather than a scientific mission. These are the first attempts at planetary exploration for the Japanese.

The 1969 space cooperation agreement with the United States requires Japan to use U.S.-derived space technology only for peaceful purposes, and a 1969 resolution passed by the Diet also states that Japan will engage only in "peaceful" space activities. There is a continuing debate over whether reconnaissance and communications satellites would be counted as "peaceful" since they are used by the military, even though they are non-aggressive. In 1983, the Japanese Government approved plans for the military to use the CS2 communications satellite, but internal debate in Japan continues.

TABLE 11. Japanese Space Launches

Name	Launch Date	Launch Site	Comments
Osumi Lambda 4S-5	02/11/70	U	Test flight.
Tansei MS-T1	02/16/71	U	Test flight.
Shinsei SS-1	09/28/71	U	Science.
Denpa REX SS-2	08/19/72	U	Launch success, payload failure.
Tansei 2 MS-T2	02/16/74	U	Test flight.
Taiyo SRATS	02/24/75	U	Science.
Kiku ETS 1	09/09/75	T	Test of new N launch vehicle.
Ume ISS	02/29/76	T	Launch success, payload failure (for science).
Tansei 3 MS-T3	02/19/77	U	Engineering test.
Kiku ETS 2	02/23/77	T	First Japanese launch to test geostationary orbit; satellite.
Kyokko (Exos A)	02/04/78	U	Science.
Ume 2	02/16/78	T	Ionospheric sounding.
Jikiken (Exos B)	09/16/78	U	Science.
Ayame 1 (ECS-1)	02/06/79	T	Failed to reach geostationary orbit.
Hakucho (Corsa B)	02/21/79	U	Science.
Tansei IV	02/17/80	U	Test satellite.
Ayame 2 (ECS-2)	02/22/80	T	Failed to reach geostationary orbit.
Kiku-3 (ETS-4)	02/11/81	T	Engineering test.
Hinotori (Astro A)	02/21/81	U	Science.
Himawari 2	08/10/81	T	Weather.
Kiku -4	09/03/82	T	Engineering test.
Sakura (CS-2A)	02/04/83	T	30/20 GHz communications.
Hinotori (Astro B)	02/20/83	U	Science.
Sakura (CS-2B)	08/05/83	T	30/20 GHz communications.
Yuri 2A	01/23/84	T	Operational 30/20 GHz communications.
EXOS C	02/14/84	U	Science.
Himawari 3	08/03/84	T	Weather.
Sakigake (MSTS)	01/08/85	U	Halley's Comet probe.
Suisei (Planet A)	08/18/85	U	Halley's Comet probe.
BS2B	02/12/86	T	Communications.
Ajisai; Fuji	08/18/86	T	Test of new H 1 rocket. Ajisai is geodetic satellite; Fuji is for amateur radio.
Ginga (Astro C)	02/05/87	U	X-ray astronomy.
MOMO	02/19/87	T	Ocean remote sensing.
ETS-5	08/27/87	T	Test of H-1 rocket.
Sakura (CS-3A)	02/19/88	T	Communications.
Sakura (CS-3B)	09/16/88	T	Communications.
EXOS-D	02/22/89	U	Scientific satellite (auroral studies).
GMS-4	09/06/89	T	Weather.

Does not include launches of Japanese satellites by other countries. For launch failures prior to 1977, see *World Wide Space Activities* (House Science and Technology Committee, 1977). p. 203. Prepared by CRS. Launch dates are in Greenwich Mean Time. U = Uchinoura; T = Tanegashima.

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE SPACE EXPLORATION.

Reproduced from Beyond Earth's Boundaries: Human Exploration of the Solar System in the 21st Century, 1988 Annual Report to the Administrator; by The Office of Exploration, National Aeronautics and Space Administration. Washington, The Administration, 1988. p. 7-12, 30-50.

In June 1987, the NASA Administrator established the Office of Exploration in response to an urgent national need for a long-term goal to energize the U.S. civilian space program and stimulate the development of new technology. This demand had its origins in a recently intensified emphasis on long-range program planning, which was given new impetus by two reports.

In 1986, the National Commission on Space published its report, "Pioneering the Space Frontier." This Commission was appointed by the President and mandated by Congress to formulate a visionary agenda to lead America's civilian space enterprise into the 21st Century. After conducting detailed research and hearing nationwide testimony, the Commission recommended to the Nation a bold plan: "To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars."

Later that year, the NASA Administrator asked scientist and astronaut Sally Ride to lead a task force to look at potential long-range goals of the U.S. civilian space program. The program was then at a crossroads, aspiring toward the vision of the National Commission on Space, but faced with the realities set forth by the Rogers Commission. It was critical for NASA to respond aggressively to the challenges of both, while recognizing the necessity of maintaining a balanced space program within reasonable fiscal limits.

The task force report, "Leadership and America's Future in Space," was released in August 1987. The report identified and reviewed four initiatives that could direct the civilian space program to a position of leadership in a particular sphere of space activity. The four initiatives were: (1) Mission to Planet Earth, elements of which NASA's Office of Space Science and Applications is now pursuing; (2) Exploration of the Solar System, robotic missions also being pursued by the Office of Space Science and Applications; (3) Outpost on the Moon; and (4) Humans to Mars.

The Office of Exploration originated from the group's recommendation that NASA establish a focal point to fund, lead, and coordinate studies of human exploration of the solar system. Building on the two initiatives featuring piloted exploration – Outpost on the Moon and Humans to Mars – the Office now heads a NASA-wide effort, the goal of which is to identify viable alternatives and provide recommendations for an early 1990s national decision on a focused program of human exploration.

The intent of this effort is two-fold. First, we seek to develop a mature understanding of the available opportunities and options. Second, we want to use that understanding to define and stimulate judicious investments in required near-term NASA programs. The investments made today will position this Nation to wisely choose and pursue a strategy for human exploration, and will enable significant accomplishments before the end of the first decade of the 21st Century.

The choice of a program for human exploration is an important one, and one that must be made carefully. We are looking at a wide range of opportunities and their interaction with the complex set of elements – technology, life sciences research, robotic precursor missions, transportation capabilities, in-orbit assembly, extraterrestrial systems, and others – that delineate the range of possibilities.

This document is an annual report describing work accomplished in developing the knowledge base that will permit informed recommendations and decisions. An in-depth discussion of this year's studies is available in a separate three-volume series titled, "Exploration Studies Technical Report: FY 1988 Status."

PATHWAYS TO HUMAN EXPLORATION

National space policy has established the goal of human expansion into the solar system, but beyond that, no specific guidelines exist regarding the pathways, timing, or concentration of purpose. We could go to the Moon, or to Mars and its moons, or we could go first to the Moon, and then on to Mars. We could choose a plan for permanent habitation, or one for a faster mission with no lasting facilities. Intellectual reasons for exploration could dominate, or a desire for commercial gain could prevail. To formulate a logical plan to achieve the goal of human exploration, it is important to first identify and comprehend the rich array of possibilities before us. Developing a philosophical viewpoint that articulates our underlying motivation will direct the more pragmatic aspects of our activities as we progress toward meeting our objectives.

During a period of intense competition for Federal resources to support major science and technology research programs, it is imperative that NASA present a compelling case for the important role that human space exploration performs for the Nation. As NASA's first Administrator, T. Keith Glennan, once commented, "How can we decide how important it is to spend, on an urgent basis, the very large sums of money required to put man into orbit or to explore the atmosphere and surface of Mars or Venus unless we have a pretty firm grasp on what the purpose behind the whole space effort really is? . . . who is thinking about (this) and doing something about developing some answers?"

To begin to address these questions, we have reviewed seven major themes and rationales for exploration: national pride and international prestige, advancement of scientific knowledge, technology catalyst, economic benefits, space enterprise, international cooperation, and education and excellence. An awareness of the ways in which meeting the objectives embodied in these themes can be especially enhanced by human intellect, energy, and participation helps to guide the selection of potential pathways for human exploration.

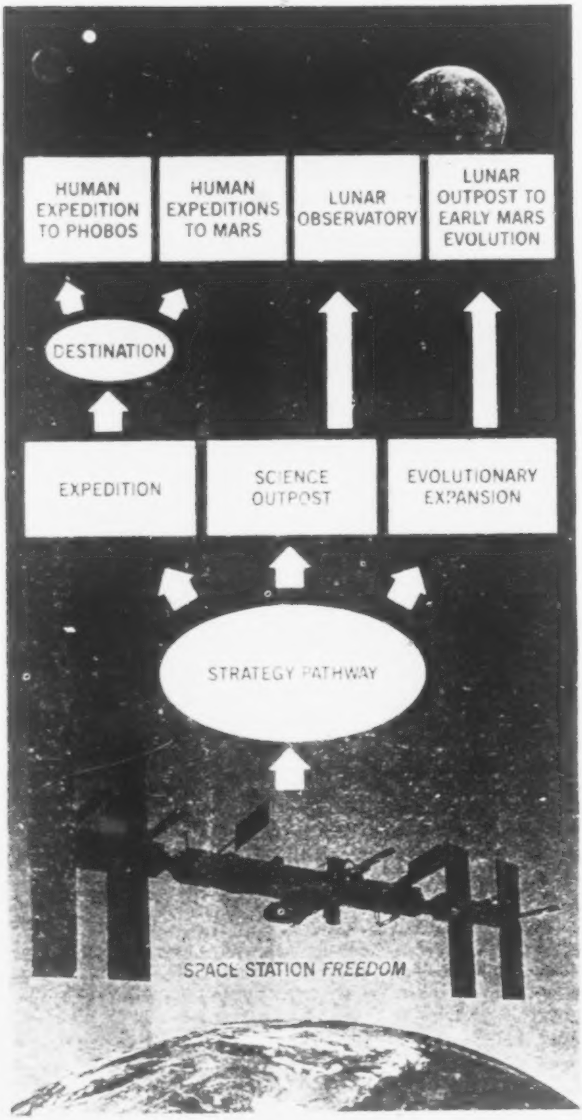
Each proposed human exploration scenario must be examined in terms of how it satisfies the themes or rationales for which such missions are intended and undertaken. In order to elicit and sustain widespread support for our long-range goals, we must understand these concepts in light of the fundamental values held by our society.

An extensive range of possibilities exists for human exploration and development of the Moon and Mars. To organize and systematically examine a full spectrum of options, we identified three strategies, or alternative pathways, for study this year. Each strategy presents particular opportunities for satisfying defined exploration themes and objectives. In the coming years, additional pathways will be developed to expand the set of options.

The first strategy addresses ***human expeditions,*** emphasizing a significant, visible, successful effort to establish the first human presence on another body in the solar system. The expeditionary pathway would lead to exploration without the burden and overhead

The worlds of the inner solar system, in particular the Moon and Mars, hold out their mysteries and their riches for our exploration. We have only to decide where and when to go, and what we wish to achieve when we arrive.

FIGURE 1. Exploration Pathways



associated with lasting structures and facilities. This pathway has been explored for missions to Mars and its moons.

Establishing a ***science outpost***, the second strategy, emphasizes advancing scientific knowledge and gaining operational experience by building and maintaining an extraterrestrial outpost as a permanent observatory. Such a facility, located far from the obscuring effects of Earth's turbulent atmosphere, would tremendously enhance our long-term astronomical studies. The experience gained in the process would serve as a foundation for establishing a permanent human base on another planetary body. This pathway has been explored for a mission to the Moon.

The third pathway, ***evolutionary expansion***, would sustain a methodical, step-by-step program to open the inner solar system for exploration, space science research, extraterrestrial resource development, and, ultimately, permanent human presence. This strategy would begin with an outpost on the Moon and progress to similar bases of operations on Mars and its moons.

Figure 1 depicts these three pathways for human exploration of the Moon and Mars. All roads begin with Space Station *Freedom*, as an essential base for conducting life sciences research and for learning to build and operate large facilities in space. *Freedom* is also required as a transportation depot, where space transfer vehicles will be assembled and fueled, and from which crew members will embark on their interplanetary journeys.

For each of the three exploration pathways, candidate missions were identified to be systematically examined as "case studies," in order to obtain an understanding of the implications of the potential approaches to exploration. Four candidates were developed: (1) Human Expedition to Phobos, (2) Human Expeditions to Mars, (3) Lunar Observatory, and (4) Lunar Outpost to Early Mars Evolution.

Within the case study framework, detailed mission analyses and system engineering studies were performed to define a full set of concepts and requirements for each case. These analyses included an assessment of required environmental and scientific data, Earth-to-orbit transportation needs, necessary in-space support facilities and systems, in-orbit vehicles and assembly facilities, requisite life sciences research, advanced technology requirements, and provisions for systems and activities to be conducted on the surfaces of planetary bodies.

The case study effort includes producing actual system design concepts for implementing such missions. This approach builds a context within which diverse exploration strategies can be developed, analyzed, and assessed. Through building this knowledge base, it becomes possible to refine these options in the future.

CASE STUDY RESULTS AND ASSESSMENT

A variety of new vehicles must be developed to support a highway to space. This artist's conception shows a possible design for an orbital transfer vehicle, which could ferry crew and equipment between an Earth-orbital transportation depot and the Moon.

The knowledge that we sought to gain through this year's case studies lies in the areas of defining benefits returned, understanding technical requirements, and assessing near-term programs. The four cases were formulated with a consistent methodology and to a uniform level of detail, in order to compare and contrast diverse exploration strategies. As technical details and requirements began to emerge, it became possible to identify essential near-term investments in Earth-to-orbit transportation, life sciences research, robotic precursor missions, Space Station *Freedom* utilization, and technology. In many areas, the requirements are common to all case studies; therefore, programmatic readiness to meet these needs can and must be assessed before any choice of initiative is made. A key finding is that these foundation programs are pacing elements, which must begin soon in order to prepare this Nation to conduct human exploration missions in the next century.

CASE STUDIES

To develop a strong knowledge base of exploration pathway sensitivities, we selected case studies that encompass a broad range of objectives, requirements, and capabilities. All four address the prime directive of expanding human presence and activity beyond Earth orbit and into the solar system, but emphasize a different pathway, destination, or basic approach. The strategies range from one-mission expeditions to a long-term evolutionary approach. Some mission designs use existing technologies or those that will be available in the near future; others require highly sophisticated new developments. The earliest mission, to Phobos, could arrive in 2003; we could go to the Moon in 2004; and we could arrive at Mars in 2007, or as late as 2014 in the evolutionary case.

Case study results exhibit significant contrasts between expeditionary and evolutionary approaches. Expeditions are very transportation-intensive, and the major focus is on the systems and facilities required to get to the destination. For longer-term programs, operational transportation requirements are more modest and steady, and the focus is on sustained activities and systems on planetary surfaces.

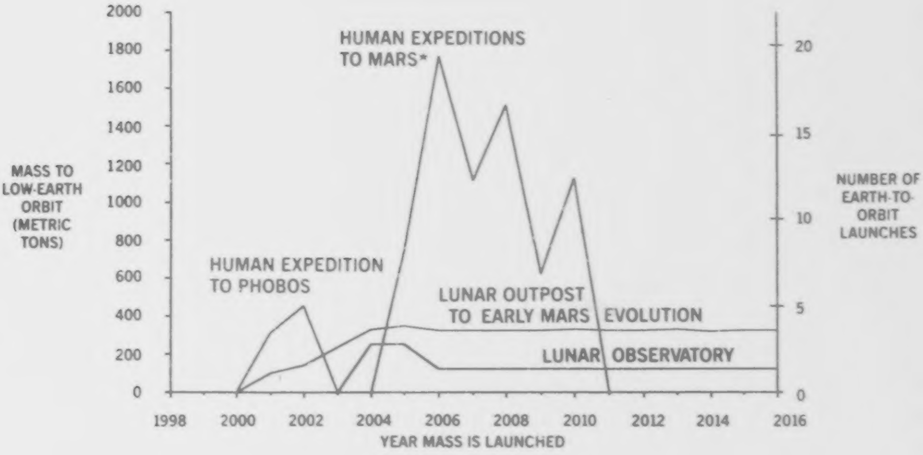
Although each case possesses its own unique attributes, some characteristics can be compared directly. For example, the annual mass to low-Earth orbit delivery requirement is important, since it directly affects the nature of necessary Earth-to-orbit transportation systems and Earth-orbital support facilities; furthermore, it is a first-order indicator of cost. **Figure 2** illustrates this requirement for all four case studies, along with the approximate annual number of separate heavy-lift launches. The figure demonstrates that large peaks in mass, corresponding to the year chosen for launch, characterize expeditions. In contrast, both the Lunar Observatory and the Lunar Outpost to Early Mars Evolution cases are characterized by steady rates of much lower magnitude. All cases, however, require large total amounts of mass to be lifted to low-Earth orbit.

Another fundamental feature of human exploration missions is the need to assemble spacecraft and perform other operations in low-Earth orbit. Projecting our current experience with in-space assembly to the level required for human exploration is extremely difficult. Design expertise developed to assemble Space Station *Freedom* will provide significant insights, and the sophistication of available automation and robotics technology that can be used to assist with, or even perform, assembly operations will also be a deciding factor. In general, the areas of construction, assembly, mining, production, and operations in space and on extraterrestrial bodies present the least understood and most challenging technologies and techniques encountered.

To provide cases where the exploration is not limited by our uncertainty of operating in low-Earth orbit, the Human Expedition to Phobos was studied in a configuration that required minimum mass in low-Earth orbit. Even so, some space assembly is required, as is the transfer of propellant between a delivery vehicle or orbital tank facility and the Phobos spacecraft.

Although minimizing in-space assembly operations might be expedient to allow an interim, early mission, for evolutionary cases we envision reusable vehicles and the use of lunar oxygen for

FIGURE 2: Case Study Requirements



*MASS REQUIREMENT FOR 1988 CONFIGURATION NOT CONSIDERED PRACTICAL, ALTERNATIVE APPROACH BEING DEVELOPED propellant and life support, plans that assume a high degree of proficiency in space operations and maintenance.

A basic issue arises from the trade that exists between assembly and transportation to low-Earth orbit: should this Nation concentrate its attention on expanding the pre-integrated mass-delivery capabilities of individual Earth-to-orbit vehicles, or should we direct our efforts to developing new technology and systems to perform significant amounts of assembly and related operations while in orbit? A complex set of interrelated parameters will determine the degree to which in-space assembly is used, but in any case, the need to bring large total quantities to orbit dictates a requirement to invest in the development of new, more capable launch vehicle systems.

We can also concentrate on minimizing the mass that must be lifted from Earth. For example, aerocapture for Mars missions can reduce that amount by about 50 percent. This technique involves the use of a large, saucer-shaped structure (an aerobrake) that is assembled in orbit. When the planet's atmosphere is reached, the spacecraft employs the resistance generated by the aerobrake to slow the vehicle down and maneuver it into orbit; little fuel is expended other than that required for attitude control. This reduces the necessary amount of propellant that must be lifted from Earth; however, the aerobrake technology must be developed, and the aerobrake itself must be assembled in orbit, also a technology challenge.

Reducing mass to low-Earth orbit stimulates other requirements in advanced technology. For example, missions to Mars benefit significantly if advanced systems, such as nuclear thermal rockets or nuclear electric propulsion, are used. These technologies take time to develop, and we must expedite our choice of an appropriate direction in which to concentrate our investments. In addition, nuclear power systems will introduce new operational requirements, complexities, and safety considerations.

The amount of mass that must be lifted from Earth for human missions to Mars can be reduced by as much as 50 percent if a structure called an aerobrake is employed. The Mars landing vehicle depicted here uses a "molly bolt" design that allows the aerobrake to be deployed in a flat shape for atmospheric entry and landing, and then retracted to form a smooth conical shape for ascent.

HUMAN EXPEDITION TO PHOBOS

If the direct route from Earth to Mars is the selected exploration strategy, a Human Expedition to Phobos appears to be a productive interim step that would provide early experience and bring us to the surface of another world more than four years earlier than a mission to the surface of Mars. Assuming the use of aerocapture for both missions, the amount of mass that would need to be carried to low-Earth orbit for the Phobos case is approximately one-third that required for a single Mars mission. Assessments of required technology indicate that the mission to Phobos can be accomplished if we assume the existence of technology already planned for that time frame, and emphasize selected new areas, such as aerobraking, cryogenic propellant transfer and storage, and technologies associated with long-duration human spaceflight.

In the process of evaluating this case, we uncovered additional promising results that indicate that the scale of the vehicles and the mission can be reduced even further. The Earth launch requirements

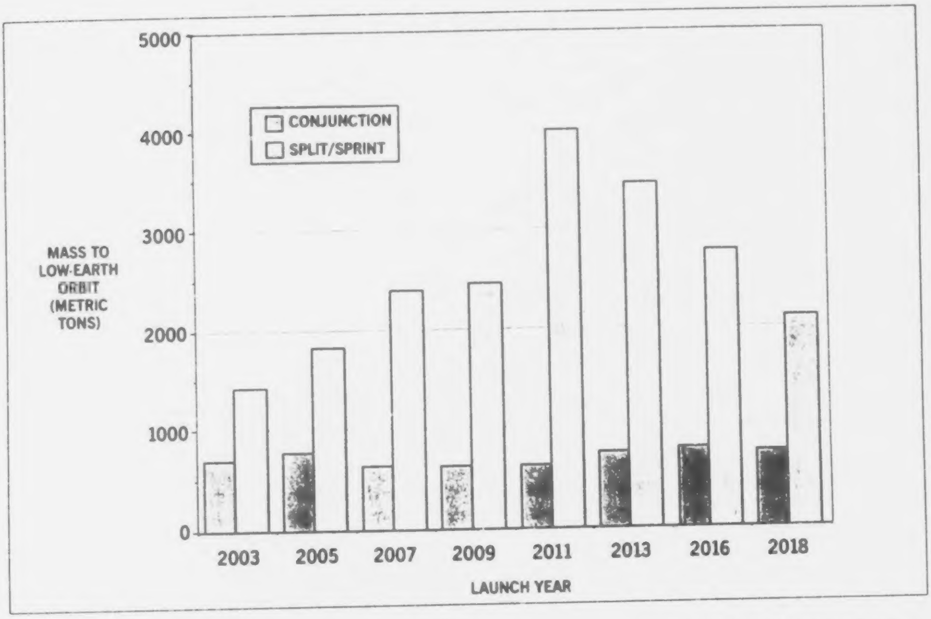


FIGURE 3: Effect of Mission Date on Mass Required in Low-Earth Orbit

can be brought within a practical range for Shuttle-derived vehicles by using aerobraking at Mars, using an integrated Earth launch vehicle/Mars transfer vehicle approach, and reducing the number of crew members.

The expedition to Phobos also serves as an excellent precursor to a later Mars landing. If the capability is developed for aerobraking at Earth, which allows reuse of vehicles, this case could evolve to a subsequent Mars landing, also without exceeding the capacity of launch vehicles derived from Space Shuttle components. An evolutionary strategy could be realized by taking a modular approach to the vehicle stages and using longer trip times (building on the experience acquired during the shorter trip to Phobos) for a Mars landing mission and subsequent evolutionary missions. In the coming year, additional study and analysis will further explore the merit of these promising results.

HUMAN EXPEDITIONS TO MARS

An expedition directly to Mars is very transportation-intensive, particularly if we seek landing opportunities at the end of the first decade of the next century. The choice of landing opportunity is important, because the performance and requirements for piloted sprint-class trajectories to Mars can vary widely with launch year and corresponding celestial geometry. **Figure 3** illustrates this sensitivity:

initial required mass to low-Earth orbit can fluctuate by as much as 60 percent. This phenomenon has a profound effect on designing spacecraft with adequate resilience to launch delays from one Mars opportunity to the next (26 months); the implications on program cost of designing a common interplanetary transport capable of capturing the mission in several consecutive opportunities are enormous. Therefore, optimum launch opportunities must be protected, or options must be developed that are less sensitive to Earth-to-Mars launch year.

Because of the number of Earth launches, the level of in-space assembly and fueling operations and the resulting cost, and the required short stay times (less than 30 days) at Mars, this case cannot be considered practical in its current form. In the coming year, much additional work will be directed toward reducing the scale of this mission. Techniques will be evaluated that involve more energy-efficient flight paths and longer stay times, advanced propulsion technologies, and incremental strategies as described for the Phobos case.

Additional analysis of robotic precursor requirements is also needed, so that we may better isolate essential precursor investments from those that enhance. Because these investments can be substantial, and the timing of required results can pace the schedule for the development of piloted missions, this analysis is critical.

Planning for the Human Expeditions to Mars also involves substantial new technology development, and unknowns of both large-scale construction and assembly in orbit.

LUNAR OBSERVATORY

The human-tended Lunar Observatory case indicates that we could establish and operate a significant scientific outpost on the Moon with a comparatively small and constant mass to low-Earth orbit. The facility could be delivered and maintained with one to two round-trip flights per year, which is compatible with Shuttle-derived launch vehicle capabilities and places minimal growth demands on Space Station *Freedom*. Science instruments, associated low-Earth orbit and lunar surface assembly and construction techniques, and the crew's ability to perform these surface operations within a 14-day stay require additional technology and operational capability and experience.

A scientific outpost on the Moon can be a productive step toward building a permanent lunar base. The evolutionary expansion process benefits from the acquired operational experience, as well as from the actual structures and facilities that would be developed. In the coming year, we will cultivate a more intense involvement with the scientific community to fully evaluate the scientific potential of this case. In addition, we will examine the idea of including the Lunar Observatory as part of an evolutionary lunar base strategy.

LUNAR OUTPOST TO EARLY MARS EVOLUTION

The evolutionary case study demonstrates the benefits to be accrued by using extraterrestrial resources in a long-term, sustained program. Both Mars cases – the expedition and this evolution – send three piloted flights to Mars, but this evolutionary case could accomplish a Mars mission using 30 percent less mass to low-Earth orbit. The evolutionary approach appears feasible with a sustained annual mass investment that is much lower than the surge required for a direct Mars expedition; however, this savings may be offset by the required investment in facilities on the Moon. Much detailed analysis and refinement of this concept are required, especially concerning the necessary investments in technology, advanced transportation vehicles, and surface systems, before the true benefits of extraterrestrial resource use can be accurately evaluated.

The Moon can also be used as a "learning step" for exploring Mars. The lunar environment provides an opportunity to learn to live and work on another world, and to adapt to the confined, hostile environment of space. With all the unknowns associated with long-term human exploration, the Moon offers a partial-gravity extraterrestrial research base only three days' journey from Earth, and can be used as a base for developing knowledge of what is required for a long-duration mission to Mars.

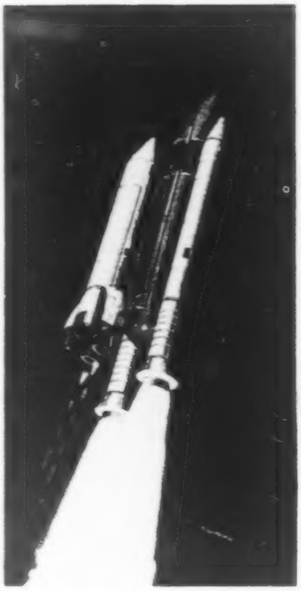
Although we have really only begun to develop and analyze this case, it shows considerable promise for scientific and exploration benefits and opportunities, as well as having the budgetary and policy advantages of a reduced and essentially constant annual requirement of resources. In the coming year, this evolutionary strategy will be analyzed in greater detail.

ASSESSMENT OF NEAR-TERM PROGRAMS

The contrast among the four case studies is not surprising; strategies were deliberately selected to cover a broad range of objectives, options, and requirements, in order to gain a deeper understanding of the fundamental needs of human exploration. The interesting conclusion about these cases, however, is that all have similar and common characteristics when viewed in terms of prerequisite foundation programs. Additional investments in existing programs are required in order to enable a full range of possibilities in the next century and to establish the foundation for human exploration; these investments share a high degree of commonality across all cases.

EARTH-TO-ORBIT TRANSPORTATION

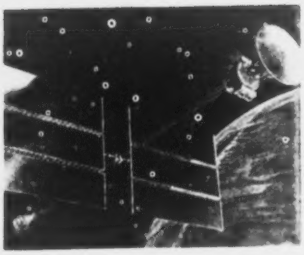
All human exploration missions will require the delivery of substantial mass to low-Earth orbit (see Figure 2); clearly, our present launch capability must be augmented. To meet the cargo transport requirements for the 1988 configuration of the Mars expeditions (Case Study 2), launch systems with an annual payload capacity for several million pounds would be required. Preliminary studies indicate that to reduce Earth-orbit operations requirements to a reasonable level, vehicles with an individual payload capacity of up to 91 metric tons (200,000 pounds) should be developed. Still, this assumes that a significant amount of in-orbit assembly is possible, an assumption that must be validated with further study.



This Shuttle-derived system concept would use existing components to significantly increase our payload capability to low-Earth orbit for unpiloted launches.

In order to meet the early Mars expedition requirements, a vehicle in the 91 metric ton class must become operational by approximately 2000. Transportation requirements for the Phobos expedition and the Lunar Observatory are much lower, and could be satisfied by an interim augmentation to the launch capacity of Shuttle-derived vehicles. As currently defined, the evolutionary case is slightly beyond this capability, and additional analysis is necessary to understand how the early phasing of the lunar buildup might be impacted if this case were initially constrained to use a Shuttle-derived launch vehicle. Studies in the next year will emphasize reducing the mass requirements, and phasing interim and advanced launch systems for exploration cases. An interim heavy-lift capability would also be advantageous for supporting prerequisite technology demonstrations and robotic precursor missions in the middle to late 1990s.

Personnel transport solutions are still under study, but enhancement of current Space Shuttle capabilities is needed, and various methods of increasing that capability must be examined. The exact degree to which enhancement is required depends on the amount of in-orbit assembly and processing that the crew must perform. Crew transport (and in-orbit accommodations) could present a major issue if significant numbers of crew members are required in addition to dedicated Space Station *Freedom* personnel. A substantial study effort is required in the next year to understand these needs and their associated sensitivities.



One concept for a vehicle to provide an artificial-gravity environment for Mars exploration crews. As shown here, the piloted vehicle is rotating around the axis that contains the solar panels. Levels of artificial gravity vary according to the tether length and the rate at which the vehicle spins.

LIFE SCIENCES RESEARCH

To permit safe, productive, lengthy stays in space, a life sciences research program to assess, understand, and alleviate the effects of long-duration spaceflight on the human physiological and psychological condition is of primary importance. In general, missions to the Moon are less demanding of prerequisite life sciences needs, primarily because of short flights and stay time, and the ability to use the Moon as a "real-time" life sciences laboratory, as in the evolutionary case (Case Study 4). Analysis indicates that with continued investment in the ongoing life sciences base research program, combined with planned research in support of Space Station *Freedom*, the Lunar Observatory and the Lunar Outpost to Early Mars Evolution cases could be initiated without additional precursor human research. (For the evolutionary case, the research required for the Mars journey is conducted during the lunar outpost phase.)

To support direct expeditions to Mars (Case Studies 1 and 2), additional prerequisite research is required in such areas as artificial gravity or low-gravity countermeasures, space human factors, long-duration health maintenance, and radiation protection. A very significant factor affecting vehicle design and crew capability is the long-term gravity environment that can safely be tolerated by the crew.

There is currently substantial uncertainty that the zero-gravity countermeasure program will provide approaches that are satisfactory for long-duration spaceflight. Thus, an artificial-gravity research program pursued in parallel with our zero-gravity countermeasures program is a high-priority need. The results of this research must be available by 1998 to maintain a first-decade landing schedule; therefore, the lead time required dictates that this research should begin no later than FY 1990. Maintaining cooperation with the U.S.S.R. in life sciences research is essential, as this collaboration can give early indications of the zero-gravity countermeasure program's probability of success.

ROBOTIC PRECURSOR MISSIONS

Human exploration of the Moon and Mars mandates a varying number and scope of robotic spacecraft missions (precursors) that collect information to characterize planetary environments. Such missions define the conditions in which spacecraft and crew must function by acquiring valuable scientific and engineering data. Robotic missions also serve as technology and engineering demonstrations for such capabilities as landing accuracy, aerocapture at Mars and Earth, surface mobility, and autonomous rendezvous and docking. In addition, the robotic precursors demonstrate incremental capability and achievement, providing important interim milestones in a very long program. An added benefit is that building on the tradition of international cooperation through jointly conducted robotic space science missions can serve as a foundation of near-term experience toward potential cooperation involving longer-term human exploration ventures.

Specific precursor requirements for case studies have been defined. The Phobos expedition requires the scientific and engineering data that the U.S. *Mars Observer* (1992 launch) and the Soviet *Phobos* mission (launched in July 1988) will obtain. The Soviet probe will be the first detailed survey of Phobos; depending on the results, other precursors may be needed.

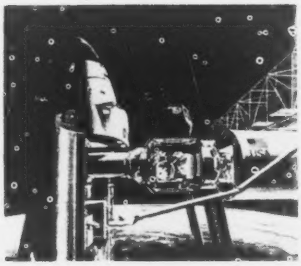
The direct Mars expedition also depends on the *Mars Observer* and *Phobos* missions. For engineering considerations, additional precursors must refine our model of the atmosphere (and demonstrate Mars aerobraking), and complement our knowledge of mechanical and soil properties on the Martian surface. To support scientific exploration, additional missions will clarify the science opportunities that can be expected and will help to develop the types of tools and techniques that can be employed in human investigations. Robotic precursors will be examined in the next year to understand mission requirements and optimum configurations.

For the Lunar Observatory, information is needed to aid in the selection and characterization of the observatory site; a modification to the currently planned *Lunar Observer* appears to provide the required data.

The *Lunar Observer* also provides site characterization data and global resource survey data relevant to the lunar phase of the

The *Lunar Observer*, proposed for launch in the mid-1990s, will obtain much of the information necessary to return human explorers to the Moon. The mission would map the Moon from orbit for a full year to provide complete global information about surface chemistry, mineral composition, surface features, topography, gravity, and magnetism.

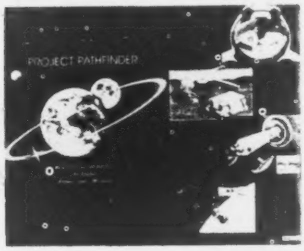
evolutionary case. Locating areas with high concentrations of resources is of utmost importance for supporting the lunar base. Depending on resource survey results, additional precursors (possibly sample returns) may be necessary in order to understand the resource extraction process that should be planned for the lunar base. Only a small part of the Moon has been mapped for resource availability and concentration; we are particularly interested in searching for areas that may hold hydrogen or water. For the Mars phase, a sample characterization of Phobos is a necessary adjunct to resource extraction development. As for any human missions to Mars or its vicinity, the *Mars Observer* and the *Phobos* missions are essential precursors for the Lunar Outpost to Early Mars Evolution case.



This artist's conception portrays a close-up view of a Space Shuttle docked to the permanently manned Space Station *Freedom*. The Shuttle is attached to a pressurized resource node that permits the transfer of crew and equipment.

SPACE STATION *FREEDOM*

As a base to gain long-duration operations experience, to conduct life sciences research, and to function as a testbed to demonstrate technology, Space Station *Freedom's* contributions to human exploration of the solar system will be monumental. Bringing these capabilities to operational status within the currently planned schedule will do much to protect our long-term options. Since Space Station *Freedom* will eventually serve as a transportation depot, it is certainly not too early to begin now to define the exploration requirements for *Freedom*. The scale of these requirements will be driven in large measure by whether the initial destination is the Moon or Mars. Therefore, in order to have the appropriate capabilities in place by the time they are needed, a pathway decision in the early 1990s is important. Space Station *Freedom* may also play a role in the development of artificial-gravity facilities; the life sciences research mentioned earlier needs to begin by 1990 to determine this. At this time, the key considerations are to begin to define reference evolution configurations consistent with our exploration case study requirements, and to develop the advanced technology that ensures readiness to enhance Space Station *Freedom's* capabilities at the turn of the century.



Project Pathfinder is developing technologies that are essential to extended human space travel.

TECHNOLOGY

A key element of our near-term investment strategy is to refine and focus the development of technologies required for human exploration through Project Pathfinder, which is pushing advanced technology in the areas of surface exploration, in-space operations, propulsion, nuclear power systems, aerobraking, automation and robotics, humans-in-space, space transfer vehicles, and many others. Because the period between initiation of technology development and readiness for actual mission application can run from eight to twelve years, it is imperative that we sustain our commitment to this advanced technology endeavor. In order to contribute to eventual mission design, the Pathfinder technologies must achieve the necessary degree of readiness by the late 1990s. **Figure 4** illustrates key technologies as evaluated in relation to the four case studies. Those technologies that are required are indicated by a circle in the appropriate column; critical pacing elements are printed in green.

FIGURE 4: Assessment of Prerequisite Technology

CRITICAL TECHNOLOGY	Human Expedition to Phobos	Human Expeditions to Mars	Lunar Observatory	Lunar Outpost to Early Mars Evolution
Cryogenic Fluid Management	●	●	●	●
Automated Rendezvous and Docking	●	●	●	●
Autonomous Rovers		●		●
Mars and Earth Aerocapture	●	●	●	●
On-Orbit Assembly and Construction		●	●	●
Surface Extravehicular Activity Suits		●	●	●
Surface Power (including SP-100)		●	●	●
Advanced Chemical Propulsion	●	●	●	●
Nuclear Electric Propulsion				●
In-Situ Propellant Production				●
Advanced Life Support	●	●		●

In addition to component development, certain technologies will require major ground or flight demonstrations as part of the program development process. These include: aerobraking demonstrations beyond the Civilian Space Technology Initiative's Aerodynamic Flight Experiment, cryogenic fluid handling in space, closed ecological life support systems, advanced fractional-gravity spacecraft prototypes, and nuclear power systems. Communications and data handling facilities may also require some augmentation to accommodate human exploration missions.

SUMMARY

The issues discussed above – case study results and program requirements – are the outcome of initial analyses of the overall scale, breadth, and complexity of human exploration options. Although our approach has demonstrated a top-level view of what is needed to accomplish missions to the Moon and Mars, much detailed research, refinement, and sustained investments are required during the next 10 years to provide the necessary foundation to enable human exploration in the first decade of the upcoming new century.

A program for human exploration of the solar system is a productive and rewarding venture, but we must bear in mind that it is not simple and it is not inexpensive. Our analyses indicate, however, that with modest, prudent, near-term investments, and sustained commitments, this long-term goal is achievable.

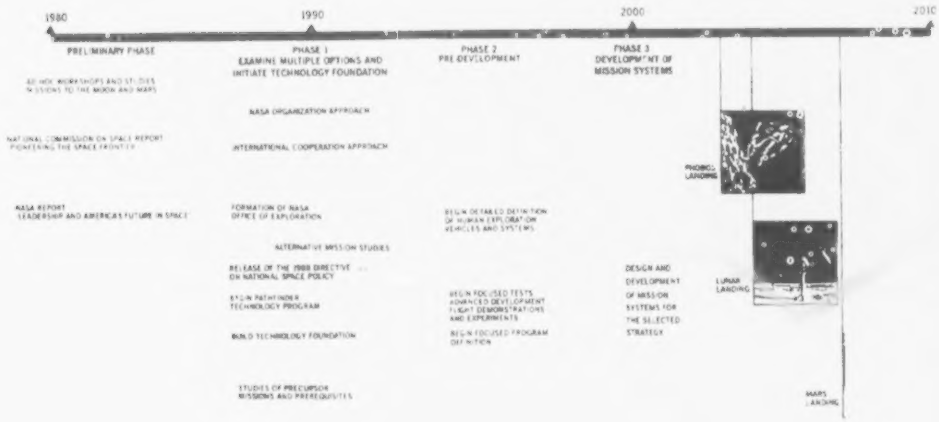
EXPLORATION PROGRAM IMPLEMENTATION STRATEGY

Developing a strategy to implement a program for human exploration of the solar system mandates the consideration of a time period of at least 20 years. Equally important are the near-term investments and studies that keep open promising options and opportunities. The implementation strategy that we have developed is built on these two fundamental factors.

A high priority is placed on positioning this Nation to accomplish exploration objectives in the first decade of the 21st Century, while, at the same time, not allowing that desire to drive required investments in the nearer term (through the 1990s) beyond levels that are considered reasonable and practical. The strategy must be sensitive to the schedules of key prerequisite programs, such as Space Station *Freedom*, which have plans extending into the late 1990s, with associated demands for technical skills and resources. Thus, our strategy must effectively build on current programs, keep the demand for exploration-unique resources at a modest level, and still preserve a capability to act in the first decade of the next century.

The program implementation strategy that meets these objectives naturally breaks into three phases: (1) defining and enabling multiple options, (2) initiating the long-lead-time development toward a specific option, and (3) developing the specific mission systems for initial exploration objectives. Each phase has defined milestones, at which points accomplishments can be reviewed and assessed. This technique is structured so that national decisions on the appropriate strategy can be made prior to proceeding to the next phase, with its increased commitment to required resources and expectations.

The strategy that we have developed is depicted graphically in **Figure 5**, and described in detail below.


1980
1990
2000
2010
PRELIMINARY PHASE
AD HOC WORKSHOPS AND STUDIES MISSIONS TO THE MOON AND MARS
NATIONAL COMMISSION ON SPACE REPORT PIONEERING THE SPACE FRONTIER
NASA REPORT LEADERSHIP AND AMERICA'S FUTURE IN SPACE
PHASE 1 EXAMINE MULTIPLE OPTIONS AND INITIATE TECHNOLOGY FOUNDATION
NASA ORGANIZATION APPROACH
INTERNATIONAL COOPERATION APPROACH
FORMATION OF NASA OFFICE OF EXPLORATION
ALTERNATIVE MISSION STUDIES
RELEASE OF THE 1988 DIRECTIVE ON NATIONAL SPACE POLICY
BEGIN PATHFINDER TECHNOLOGY PROGRAM
BUILD TECHNOLOGY FOUNDATION
STUDIES OF PRECURSOR MISSIONS AND PREREQUISITES
PHASE 2 PRE-DEVELOPMENT
BEGIN DETAILED DEFINITION OF HUMAN EXPLORATION VEHICLES AND SYSTEMS
BEGIN FOCUSED TESTS ADVANCED DEVELOPMENT FLIGHT DEMONSTRATIONS AND EXPERIMENTS
BEGIN FOCUSED PROGRAM DEFINITION
PHASE 3 DEVELOPMENT OF MISSION SYSTEMS
DESIGN AND DEVELOPMENT OF MISSION SYSTEMS FOR THE SELECTED STRATEGY
PHOBOS LANDING
LUNAR LANDING
MARS LANDING

PHASE 1: Examine Multiple Options and Initiate Technology Foundation

This is the current phase of the program, which began with the release of the Directive on National Space Policy, commitment to start the Pathfinder technology program, and the formation of the NASA exploration organization. The objectives during this period are to define and enable a number of promising options, and to initiate the lengthy process of developing the technologies required to accomplish these options. Mission and system studies for the human missions, precursor missions, life sciences research, and extensions to transportation capabilities and Space Station *Freedom* are required to build a mature understanding of exploration options and their implications. These early studies serve to refine and steer long-lead-time technology developments undertaken in near-term NASA programs. Many of the investments required to keep a wide range of options open are common across defined cases, a fortuitous characteristic that allows Phase 1 resource requirements to be kept to a very reasonable level, considering the scale of human exploration ventures.

At the completion of this phase, a comprehensive understanding of the options in terms of technical and policy benefits, as well as an estimate of costs and program schedules, will be available. The information will support a decision on a strategy of going to either the Moon or Mars first and a definition of specific objectives. Having accomplished the necessary planning and studies, an approach to international cooperation on precursor science missions and prerequisite life sciences research is also decided as part of this milestone in preparation for the actual hardware start of those programs.

A national decision on an exploration pathway is assumed to occur in the early 1990s. Delaying a decision will cause an increase in resource requirements for the parallel continuation of options, which get larger with time; a delay could also necessitate a corresponding yield on the timeline for exploration accomplishments.

PHASE 2: Pre-Development

The selection of the pathway signals the beginning of the pre-development phase of the program. During this time, we commit to and begin to develop the appropriate precursor and prerequisite missions, initiate the specific definition of extensions to the Earth-to-orbit transportation and Space Station *Freedom* programs, and begin the detailed study of human exploration vehicles and systems. Also during this time, the "proof of concept" and demonstration of selected, but significant and new, technologies and capabilities are begun. This activity includes flight tests, as well as major ground tests in system-level configurations that demonstrate capabilities and technology performance, prior to a commitment to full-scale program development.

Phase 2 is estimated to require five to seven years; at the conclusion of this period, a decision to commit to the development of the actual human exploration mission systems is appropriate. Having invested in the aforementioned studies, the result will be a mature understanding of the cost, schedule, and benefits of the missions, with a capability to build the systems in a reasonable amount of time, with low risk to cost and schedule.

Also as part of this phase, key answers to life sciences questions and concerns, as well as the characterization of the Moon and Mars, will be acquired and understood. This information potentially drives the technical and operational configuration of mission hardware, and it is thus very important to resolve these issues before committing to building the systems.

Case study analysis indicates that a Phobos expedition could be realized in 2003, a lunar base could become operational in about 2005, and a piloted Mars expedition could land in 2007. The activities conducted during the second phase of our program implementation strategy make it possible to realize these response times while keeping required resources to a modest level during the 1990s.

PHASE 3: Development of Mission Systems

Phase 3 is initiated with the actual development of human exploration mission systems and augmentations to supporting programs, such as Earth-to-orbit transportation, Space Station *Freedom*, and Operations Systems. This milestone, estimated to occur in the 1998-1999 timeframe, is the point at which a commitment to increased resources would be needed for the actual development and flight phases of the exploration program.

Overall, this strategy keeps investments to what is estimated to be a modest level through the 1990s while still making significant progress toward objectives. The necessary upturn in required resources does not occur until about the year 2000.

Although the funding levels will be a function of the actual strategy selected at Phase 2, this program implementation strategy would accommodate a selection of any one of the four case studies analyzed without changing the logic or assumptions contained in this strategy. It is anticipated that additional case studies will be examined that will also fit this general implementation plan.

APPROACH TO INTERNATIONAL COOPERATION

The most extensive international cooperative space effort to date, Space Station *Freedom* will benefit from the contributions of the European Space Agency, Japan, and Canada.

Throughout history, the achievement of challenging exploration endeavors has been a fundamental measure of leadership in the world. With the opening of space as a new frontier, a nation's ability to accomplish far-reaching objectives follows this tradition, and space is recognized as an important arena in which to demonstrate excellence and continued achievement. Although space exploration has had its elements of competition, most notably in the race to the Moon in the 1960s, it has also been an area of productive and increasingly complex international cooperation.

In the report, "International Space Policy for the 1990s and Beyond," the NASA Advisory Council Task Force on International Relations in Space concluded: "International cooperation, a feature of the civil space program from its outset, has served the foreign policy, scientific and space programmatic interests of the United States very well. It has given substance to U.S. leadership. The climate, character, and circumstances for cooperation have changed dramatically in recent years with the changing environment of international relations in space. However, cooperation will be even more important in the future although likely to change in character." The changing environment and character the Task Force was referring to include the growing capabilities of spacefaring nations around the world and the increasingly complex, multilateral endeavors being undertaken.

The National Space Policy also recognizes the value of international cooperation and calls for expanding our cooperative efforts in space. The Policy specifically mandates NASA "to promote international cooperative activities . . . that enhance the security and welfare of mankind."

In September 1988, the U.S., nine European nations, Japan, and Canada signed a multilateral agreement for the development of Space Station *Freedom*. Together, our international partners are expected to invest more than $7 billion in the program; the U.S. investment is expected to total about $16 billion. This is the largest international science and technology program ever undertaken. Space Station *Freedom* will be operated by an international crew and will provide valuable research data in the area of life sciences, a key element of any future human exploration into the solar system.

A logical outgrowth of the extensive participation of our foreign partners in *Freedom* – in its design, development, management, operation, and the research results obtained – could be cooperation in the human exploration of the solar system. Although it is premature to commit to any international cooperation at this early phase of our exploration studies, it is not too early to begin a dialogue with potential partners abroad. This is the same approach we took with Space Station *Freedom*. An early exchange of information with friends and allies across the broad range of precursor activities and plans for future manned projects will allow all concerned to determine the optimal match of interests for this endeavor. Such early involvement also helps to build a base of support among our potential partner nations, so that they can identify their interests and will be prepared to join us in moving forward.

In addition to potential cooperation with NASA's traditional partners, consideration will be given to what cooperative role the U.S.S.R. could play with the U.S. in space exploration. Initial discussions with the U.S.S.R. will be limited to robotic precursor activities, rather than the broader dialogue with friends and allies with whom the U.S. has a well-established tradition of cooperation. Under the U.S./Soviet space cooperation agreement concluded in April 1987, and amended at the U.S./Soviet Summit in May 1988, both nations agreed to exchange the results of independent national studies of future robotic solar system exploration missions as a means of assessing prospects for further U.S./Soviet cooperation on such missions. The exchange of independent national studies will include ***Mars Rover/Sample Return, Lunar Orbiters,*** and a Lunar Science Outpost, robotic missions that could serve as important precursors to future human exploration. The exchange of results of these national studies, together with a number of precursor joint activities under way, will put us in a position to assess the desirability of cooperation with the U.S.S.R. as U.S. plans for human exploration mature.

In developing NASA's own exploration case studies, we are operating under a ground rule that participation by foreign nations may be an option, depending on their interests and capabilities. As NASA's plans crystallize, we anticipate a more active dialogue with potential partners. This will follow up on the initial contact that NASA made with friends and allies, in which we outlined the current strategies for human exploration, and will help us better understand where our potential partners' interests may lie. Eventually, we will need to jointly define the approach to any cooperation on precursor missions, provisions for the exploration infrastructure, and the development of scientific payloads.

But before this Nation can determine the best responses to the many issues of international cooperation, we must first develop a strategy that articulates what we want to gain from our space exploration program. This strategy and its goal must be developed before we enter into long-term agreements with other nations.

Therefore, we are laying the groundwork for a decision on the national approach, and in parallel, paving the way for appropriate international cooperation.

RECOMMENDATIONS

A spaceship is leaving a lunar base to journey homeward to low-Earth orbit.

For the past year, we have been examining potential pathways for human exploration, determining the technical feasibility and national impact of alternative designs and approaches. We are certain that we have developed achievable concepts for human missions to the Moon and Mars. With a modest level of investment in the 1990s, the development phase of a lunar base or an expedition to Mars could begin as early as the late 1990s.

The 21st Century will be upon us in little more than a decade. To stand ready to achieve a program of human exploration, we must begin and sustain a vital effort in detailed research, technology development, and concentrated studies. A modest, near-term investment of resources will preserve our ability to pursue a wide range of opportunities at the turn of the century, and this ability is critical to United States leadership in space.

The analysis and assessment of this year's case studies have brought to light the elements of the foundation for human exploration of the solar system. This understanding allows some specific recommendations to be made.

First and foremost, the United States must maintain and nurture a strong commitment to current, ongoing NASA programs, which are the cornerstone for future human exploration.

- **SPACE STATION *FREEDOM*** is the key to developing the capability to live and work in space much longer than we do now. Future human exploration mission plans also depend heavily on *Freedom* as a transportation depot in Earth orbit. The development, deployment, and evolutionary growth of this essential link are vital to any long-term program.
- **PROJECT PATHFINDER** is a research and technology program that will enable a broad spectrum of space missions and strengthen the technology base of the U.S. civilian space program. To preserve our options for human exploration, national commitment to Pathfinder must be sustained.
- **LIFE SCIENCES RESEARCH** is the very foundation for human habitation of space, for both Space Station *Freedom* and for long-duration exploration. A vigorous base research program in life sciences must be maintained.
- **EARTH-TO-ORBIT TRANSPORTATION** is our access to space. Now that the Space Shuttle has been restored to flight status, the highway to space must be kept open, and plans for more capable Shuttle-derived launch vehicles must go forward.
- **PRECURSOR PLANETARY MISSIONS** obtain the data that form the basis for the scientific objectives of human exploration. Robotic missions provide essential information about the environments in which human explorers and their facilities must operate, demonstrate technologies applicable to piloted missions, and serve to foster international cooperative efforts. The schedule for these missions may set the timetable for human exploration.

These ongoing NASA programs will keep open a number of options. However, to broaden the range of opportunities, we must also aggressively study and pursue strategies for augmenting some key areas.

- **A HEAVY-LIFT TRANSPORTATION SYSTEM** must be pursued and targeted for operational readiness by the turn of the century. The capability to transport large quantities of mass (equipment, propellant, and personnel) to low-Earth orbit is essential. To meet our launch needs in the middle to late 1990s, some level of interim augmentation to our existing capabilities is required as well.
- **AN ARTIFICIAL GRAVITY RESEARCH PROGRAM** must be initiated in parallel with our zero-gravity countermeasure program if we are to maintain our ability to begin exploration in the first decade of the next century. If an artificial gravity environment must be provided, the accommodation of such facilities will have a significant impact on mission configuration. Therefore, this augmentation to our life sciences research program must be made by 1990, providing an answer by 1998, to allow human spaceship design to commence.
- **AN ADVANCED DEVELOPMENT/FOCUSED TEST PROGRAM** must be planned for initiation with the selection of the program pathway. It is essential to understand the performance and capability of selected new technologies, such as aerobraking, cryogenic fluid handling in space, closed ecological life-support systems, advanced fractional-gravity spacecraft prototypes, and nuclear power systems. Experience and proof of concept in these areas are critical to a decision to proceed with the development of a specific initiative.

America's civilian space program stands at the threshold of a new era of exploration, discovery, and enterprise. We can, and must, cross that threshold, and begin to build the foundation that will allow us to break free of Earth's boundaries and soar into the worlds beyond.

FUTURE HORIZONS

Astronauts break ground for the installation of a new telescope for an observatory on the far side of the Moon.

"To explore, to discover, to understand, and to apply what we have learned for the betterment of life on Earth and in space."

A program to expand human presence and activity beyond Earth's orbit and into the solar system must itself expand, beyond NASA, out into the Nation, and indeed, throughout this planet. Sending human explorers to other worlds, to live, learn, and work, has implications that will reverberate through many facets of civilization previously touched only marginally and temporarily by NASA's programs. The possibilities are exciting and as limitless as the horizons to which our vision can extend; many of mankind's long-held dreams will become realities as Earth's representatives go to explore our planetary neighborhood.

We envision the 21st Century as a time when humanity will have broken free of the physical and psychological bonds of planet Earth to live and work for extended periods on nearby bodies in our solar system. We will have taken our first tentative steps on another planet, to establish an outpost on which visitors may learn about the universe, about how to live away from Earth, and about how to make the riches of outer space part of our lives. Perhaps we will have built a permanent research station on the Moon, where our knowledge of astronomy will be increasing by orders of magnitude. There may be an exploration outpost on Mars, where we will be probing the origin of life and climatology in our solar system. We might be mining the Moon, or Mars and its moons, or Earth-approaching asteroids, for resources that can be used for venturing farther outward, for understanding and for improving the quality of life on Earth.

Our achievements will be a source of pride for our citizens, and international prestige will rise as other nations recognize our accomplishments. America will be exploring and developing a "new frontier," carrying on the tradition in which this nation had its birth – of moving boldly forward into uncharted territory. The residents of Earth will be thrilled and inspired, as in the early days of recorded history, by the tales of other worlds that our space travelers will bring home. Young people everywhere will share in the dream, and will be drawn in ever-greater numbers to participate in its realization.

Scientific knowledge will have increased at a pace commensurate with our exploration. Our program of robotic missions will have formed a scientific foundation [illegible] information about the geology, geochemistry, atmospheres, and surface characteristics of the other bodies of the solar system, thereby significantly enhancing our understanding of our own planet as a system. The new capabilities and insights that human skills, intellect, imagination, and curiosity will bring to scientific research on other worlds will tremendously enhance this foundation, and will enable us to prove or disprove many of the theories that we have developed.

The effects of long-duration spaceflight and low gravity on the physiology of human beings will be known and understood, and we will have developed techniques to ensure that we can function safely and effectively in the environment of space. Formulating creative ways to counteract the effects of the isolation that exploration necessarily imposes on our travelers will help us to better appreciate and meet our human needs. Perhaps we will have discovered life-forms on another planet, or the remnants of life from previous eons. Humanity's place in the universe will become more clear, and we might have discovered evidence that assures us that we are not now, nor have we ever been, alone.

Technological advances and developments will have contributed in boundless ways to our Nation's excellence and capability. We will be using extraterrestrial resources for manufacturing, energy, and radiation shielding on other planets and perhaps for economical uses back on Earth. The technology developed to enable human self-sufficiency on the Moon and Mars will have valuable applications on Earth, by accelerating advances in health care and medicine, environmental and resource management, construction, manufacturing, and many other areas.

Economically, our Nation and our planet will be reaping the benefits of technological and scientific progress. In fact, the character of our civilization may be undergoing some remarkable changes as exotic fuel extracted from the Moon is made available for use in nuclear fusion power plants on Earth. New industries will have arisen in response to the many requirements of habitation of space, and existing industries will have expanded as well. The technology that is developed to serve human needs in space could be the very foundation of many activities taking place in our Nation and on our planet in the 21st Century.

Our system of free enterprise will be invigorated as goods and services produced by private industry in response to this new area of the marketplace are purchased for use in space. In turn, the technology systems that are developed by the space program will be turned over to the private sector for manufacturing, housing, energy, and environmental needs. And the abundant raw materials to be found in the solar system will offer vast potential for extraterrestrial mining and manufacturing by private enterprise.

As more and more nations join together to explore space – the territory that cannot be claimed by any one nation – perhaps the narrow and artificial boundaries that exist on Earth will no longer matter. Major breakthroughs in science and technology will become possible, as the great minds and varying perspectives of many cultures combine to address the questions that face humanity in the future. Nations of the world may lay aside their differences and form alliances, not for defeating a common enemy, but for achieving a common goal.

To inspire and train the scientists, engineers, and humanists who will conduct tomorrow's space program, educational curricula throughout the world will change to encompass the new vistas revealed by our exploration. Even in their grade school years, children will be studying other planets, as well as their own, from the unique perspective of "being there." Learning about those worlds will become as integral a part of their education as reading, writing, and arithmetic. The fact that space is an endless frontier of mystery will stimulate the young people of the 21st Century to press on, to learn more, to know more. The grand theme of human exploration will allow people to be connected to something that makes excellence real and tangible.

This is our vision: humanity expanding its presence and activity beyond Earth orbit and into the solar system, fulfilling mankind's aspirations to explore, to discover, to understand, and to apply what we have learned for the betterment of life on Earth and in space.

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "Our Changing Planet: The FY 1991 U.S. Global Change Research Program," a report by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology to accompany the President's Fiscal Year 1991 Budget.

The report outlines an accelerated, focused research strategy designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policies and responses to global change can be based. Because of the importance of this area, the President is proposing a 57 percent increase in the budget for this effort for FY 1991.

The research program presented here is a key component of the President's overall approach to the global change issue. This approach has, as its central goal, the provision of a sound scientific basis for developing national and international policy on global change. The President has called for an expanded schedule of international collaboration on research, monitoring, data exchange, and a new Framework Convention on climate change. This comprehensive approach recognizes the profound economic and social implications of responding to global environmental changes and maintains U.S. leadership on this issue.

The Committee on Earth Sciences' report outlines a careful blend of ground- and space-based efforts in research, data gathering, and modeling activities with both near- and long-term scientific and public policy benefits. The report has benefited from close interaction with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Programme, and the World Meteorological Organization's World Climate Research Programme. As such, I believe the report and the process which produced it provide an exemplary model of a coordinated, integrated research strategy and a sound basis for planning. Chairman Dallas Peck, Vice Chairman Robert Corell, and their interagency committee members, associates, and staff have done an excellent job and are to be commended.

Sincerely,

DAllan Bromley

D. Allan Bromley
Director

Reproduced from Our Changing Planet: the FY 1991 U.S. Global Change Research Program; a report to accompany the U.S. President's Fiscal Year 1991 Budget, by the Committee on Earth Sciences, Office of Science and Technology Policy, Federal Coordinating Council for Science, Engineering, and Technology. Washington, The Committee, 1990. p. 1-15.

Office of Science and Technology Policy
Federal Coordinating Council for Science, Engineering, and Technology

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Executive Secretary

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Executive Summary

- Although the Earth has been changing for millions of years, dramatic recent changes such as antarctic ozone depletion demonstrate that human activities are affecting the Earth system.

- Recognizing the profound economic and social implications of responding to global environmental changes, the President has set in motion a comprehensive process designed to continue U.S. leadership on this issue. This includes an accelerated, focused research effort; active participation in international collaborative efforts intended to culminate in a Framework Convention; and a comprehensive review of potential policies and their implications.

- As the research component of this process, the U.S. Global Change Research Program is designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policy strategies and responses can be based.

- An improved predictive model of the integrated Earth system and a better understanding of human interactions with this system will provide direct benefits by anticipating and planning for impacts on commerce, agriculture, energy, resources utilization, and human safety.

- Because of the high priority attached to the U.S. Global Change Research Program, the President is proposing $1,034 million for this research effort in the FY 1991 budget, a $374.8 million or 57 percent increase over the FY 1990 level.

- This proposed budget will significantly expand research, data gathering, and modeling activities with both near- and long-term scientific and public policy benefits. It includes a carefully balanced mix of ground- and space-based research efforts that are essential given the variability of the phenomena being studied and the need to scale local processes to regional and global levels.

- For the ground-based program, the proposed budget will initiate multi-agency research thrusts in several critical areas, including the role of clouds in controlling climate, fluxes of greenhouse gases, resource responses to global change, past changes in the Earth system, and the role of human activities in global change.

- For the space-based program, the proposed budget will initiate the development of the NASA Earth Observing System, a key element in "Mission to Planet Earth," which will provide the centerpiece of an integrated international satellite program for monitoring global change, coupled with a comprehensive data and information system.

- This report summarizes the key features and budget of the proposed U.S. Global Change Research Program for FY 1991. A more detailed FY 1991 research plan will be released in the spring of 1990.

- The research program was developed by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology, in close interaction with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Programme, and the World Meteorological Organization's World Climate Research Programme.

Planning the FY 1991 Program

In *The FY 1990 Research Plan*, the CES established the following goal and objectives for the U.S. Global Change Research Program:

Goal:

To establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system.

Objectives:

To establish an integrated, comprehensive long-term program of documenting the Earth system on a global scale.

To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales.

To develop integrated conceptual and predictive Earth system models.

Planning Framework

Each year the CES will review the Program to ensure that it continues to aggressively address its goal and objectives. This process began in mid-July 1989, when CES evaluated individual agency initiatives relative to ongoing programs and the priority and evaluation framework outlined later in this section.

At a series of meetings over the ensuing months, agency representatives developed a final recommendation on the content and resource requirements for the FY 1991 Program. Subsequently, during the fall of 1989, there were extensive program reviews and discussions that led ultimately to the FY 1991 Program and budget summarized herein.

As part of these deliberations, the CES has forged increasingly effective partnerships among the Federal agencies and with the scientific community. These partnerships, the need to integrate science into the policy process, and the focus on interdisciplinary science have become the "Basic Tenets" (see box on page 7) of the CES cooperative planning process.

Priority Framework

In the preparation of *The FY 1990 Research Plan*, the CES created and implemented a multi-level priority-setting framework that was used to focus and integrate the program development and budget proposals. This framework contains three levels of priorities for the U.S. Global Change Research Program, diagrammed in Figure 1. These strategic, integrating, and science priorities focus on those research questions that will produce significant early improvements in understanding and modeling the interactive Earth system. For example, there is little disagreement that a major shortcoming of existing general circulation models is their inability to simulate the role of clouds and convective processes accurately; hence, that research is the highest priority in the Climate and Hydrologic Systems element. However, concurrent progress in high priority activities in all science elements is necessary for the Program to achieve its overall goal, although not all will receive equal emphasis.

Evaluation Criteria

Within each science element, the CES evaluated FY 1991 research initiatives, taking into account the priorities and several evaluation criteria (see box on page 10). These criteria provided a framework for designing the specific project-by-project structure that constitutes the Program (see Appendix for project listing).

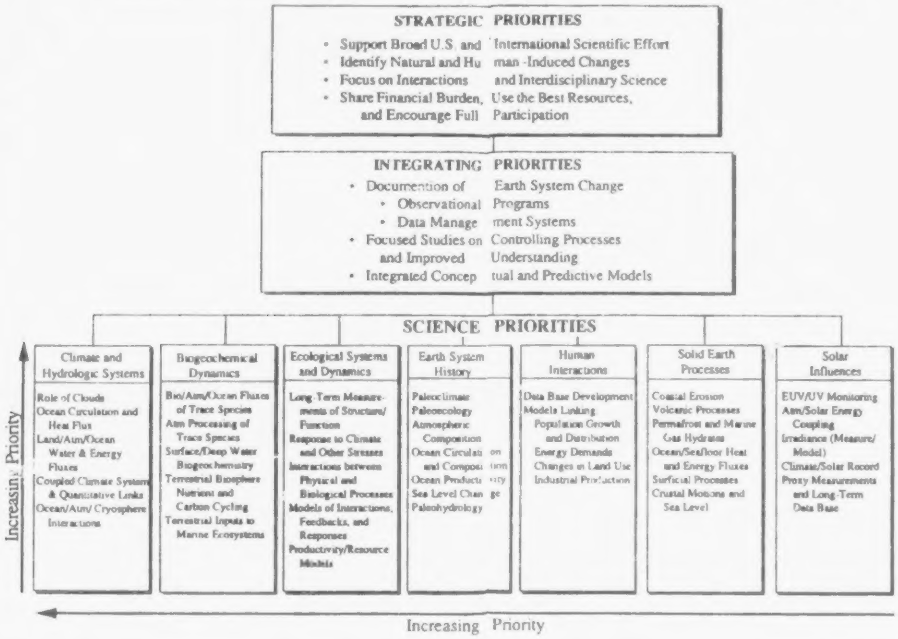
The CES Process: Basic Tenets

- ***Integrate Science into the Policy Process.*** The need for effective relationships between the policy processes of governments and the underlying science of environmental issues has always been recognized and central to the U.S. Global Change Research Program. A process for policy development has evolved within the Executive Branch that directly involves the CES, including (i) it being the focal point for the development and coordination of U.S. scientific programs for global change, both domestically and internationally, and (ii) ensuring that the results of these scientific efforts provide the foundation for rational policy debate and effective action.

- ***Maintain a Partnership Among All Participants.*** A partnership has evolved among the CES members and between CES and the non-Federal research community through the relevant Committees and Boards of the National Academy of Sciences (NAS), notably the Committee on Global Change (CGC). Within CES, there has been a conscious effort not to designate "lead" agencies. Leadership is distributed among the agencies, with each contributing its strengths to the planning, documentation, review, and implementation process. This partnership concept is fundamental to the operation of the CES. The same philosophy is operative in the parallel planning relationship with the NAS, including joint meetings, program reviews, and exchange of ideas for developing implementation strategies. In addition, the CES has interacted with (i) the international scientific community and agencies of other governments, (ii) several intergovernmental bodies with global change concerns, (iii) the environmental community, and (iv) the private sector.

- ***Focus on Interdisciplinary Science and Interactions.*** The CES science program is founded on the premise that the essential scientific questions can only be addressed through interdisciplinary research on the interacting components of the Earth system. This is also the scientific strategy of the CGC and its international counterpart, the International Geosphere-Biosphere Programme (IGBP), thereby further strengthening the interactions of the CES and CGC.

Figure 1
U.S. Global Change Research Program Priority Framework


STRATEGIC PRIORITIES
• Support Broad U.S. and International Scientific Effort
• Identify Natural and Human-Induced Changes
• Focus on Interactions and Interdisciplinary Science
• Share Financial Burden, Use the Best Resources, and Encourage Full Participation
INTEGRATING PRIORITIES
• Documentation of Earth System Change
• Observational Programs
• Data Management Systems
• Focused Studies on Controlling Processes and Improved Understanding
• Integrated Conceptual and Predictive Models
SCIENCE PRIORITIES
Climate and Hydrologic Systems
Role of Clouds
Ocean Circulation and Heat Flux
Land/Atm/Ocean Water & Energy Fluxes
Coupled Climate System & Quantitative Links
Ocean/Atm/ Cryosphere Interactions
Biogeochemical Dynamics
Bio/Atm/Ocean Fluxes of Trace Species
Atm Processing of Trace Species
Surface/Deep Water Biogeochemistry
Terrestrial Biosphere Nutrient and Carbon Cycling
Terrestrial Inputs to Marine Ecosystems
Ecological Systems and Dynamics
Long-Term Measurements of Structure/ Function
Response to Climate and Other Stresses
Interactions between Physical and Biological Processes
Models of Interactions, Feedbacks, and Responses
Productivity/Resource Models
Earth System History
Paleoclimate
Paleoecology
Atmospheric Composition
Ocean Circulation and Composition
Ocean Productivity
Sea Level Change
Paleohydrology
Human Interactions
Data Base Development
Models Linking Population Growth and Distribution
Energy Demands
Changes in Land Use
Industrial Production
Solid Earth Processes
Coastal Erosion
Volcanic Processes
Permafrost and Marine Gas Hydrates
Ocean/Seafloor Heat and Energy Fluxes
Surficial Processes
Crustal Motions and Sea Level
Solar Influences
EUV/UV Monitoring
Atm/Solar Energy Coupling
Irradiance (Measure/ Model)
Climate/Solar Record
Proxy Measurements and Long-Term Data Base
Increasing Priority
Increasing Priority

Benefits

The U.S. Global Change Research Program is founded on the premise that effective strategies to address environmental issues can be built only on sound scientific information.

Therefore, a hallmark of the Program strategy is linking the U.S. scientific program for global change to the policy process, including:

- Predicting the magnitude and timing of environmental variations, thereby providing the means to plan or avoid their impacts.
- Separating natural changes from human-induced changes, thereby balancing regulatory needs with economic and social development and providing the ability to focus on those parts of the problem that are traceable to human intervention.

Specifically, this is accomplished by supporting a robust, prioritized research effort that can address important policy issues (see box on page 13) and address public needs for predicting and dealing with environmental change through:

(i) ***Providing Timely Information*** – making available the results of scientific research through special briefings and other information products for the Congress, the Executive Branch, and others immediately after new insights are obtained;

(ii) ***State of the Science Assessments*** – providing periodic assessments of the "state of the science" in the critical areas of global change (as has been done regarding the stratospheric ozone layer), employing both domestic and international mechanisms, such as the Committees of the NAS and the Intergovernmental Panel on Climate Change (IPCC);

Benefits of the U. S. Global Change Research Program: Examples

- ***Greenhouse Gases.*** A better understanding of the processes, both natural and human-influenced, that govern the sources and fates of greenhouse gases will provide a basis for analyzing integrated control strategies and cost-benefit analyses.
- ***Ozone Depletion.*** Maintaining the "Montreal Protocol on Substances that Deplete the Ozone Layer" will require an improved knowledge of the mechanisms controlling the stability of the stratospheric ozone layer.
- ***Energy.*** Establishing links between carbon dioxide emissions and atmospheric abundances with energy policy scenarios will facilitate the assessment of different energy technologies.
- ***Agriculture/Ecosystems.*** Better knowledge of the linkages of crops, forests and other ecosystems to environmental conditions will enhance the ability to make sound decisions regarding food security, forest management, and conservation of natural resources, including crop selection, reforestation, and deforestation practices.
- ***Water Policy.*** A more complete knowledge of the interaction of the climate and hydrological cycles will help resolve issues involving water supply and demand and will allow better planning for the allocation of water resources during extreme events.
- ***Sea Level.*** Elucidation of the processes that control sea level will provide the predictive capability to guide policies regarding coastal human settlements and wetlands.

(iii) ***Regular Prediction/Forecasting Products*** - providing a line of information products that address three time scales: seasonal, interannual, and interdecadal.

- ***Seasonal Projections*** - It is expected that research already under way (including developments from the sciences associated with weather forecasting) will lead to seasonal forecasts (i.e., 30- to 60-day projections) within three to five years. These products will likely be derived from the existing weather forecasting systems operating throughout the countries of the world. Ocean forecasting is in an earlier state of development and will require increased effort to achieve this goal.

- ***Interannual Projections*** - The advent of a greatly improved understanding of how the tropical ocean induces changes in heating patterns within the atmosphere (El Niño and the Southern Oscillation) is leading toward one of the next realizable lines of predictive products. It is expected that within about 10 years regular assessments and forecasts will be produced quarterly, each providing three- to six-month forecasts, a one-year prognosis, and a two-year outlook of interannual climate variability for selected climatic processes.

- ***Interdecadal Projections*** - It is expected that prediction of selected climatic processes on interdecadal (ten to twenty years) time scales will emerge during the coming decade. The products will consist of interpretive reports and model predictions. This process is beginning with the science assessment of the IPCC and the Second World Climate Conference in late 1990.

In summary, the overall benefits of the Program are substantial: (i) providing critical data to minimize economic or other adverse impacts by supporting prudent near-term actions where justified, while accelerating the development of more reliable scientific understanding on which to base long-term policies; (ii) contributing to the Nation's environmental leadership and credibility, both domestically and internationally; and (iii) serving as a catalyst for similar scientific commitments from other nations.

SECTION 1

Executive Summary

On July 20, 1989, President Bush charted a new course for the human exploration of space:

> ". . . a long-range continuing commitment. First, for the coming decade, for the 1990s, Space Station Freedom, our critical next step in all our space endeavors. And next, for the next century, back to the Moon, back to the future, and this time, back to stay. And then a journey into tomorrow, a journey to another planet, a manned mission to Mars. Each mission should and will lay the groundwork for the next."

With these words, the President provided specificity to the goal contained in the 1988 Presidential Directive on National Space Policy: to expand human presence and activity beyond Earth orbit into the solar system. President Bush has answered the question "Where are we going?" We are going back to the Moon, and then we are going to Mars. The shape of human exploration of space is clear.

Space Station Freedom, to be followed by a return to the Moon to stay, and a subsequent journey to Mars, will be rational extensions of the United States civil space program. From its very beginning, that program has expanded human activities in space. From Mercury and on through Gemini, Apollo, Skylab, the Space Shuttle, and now, Space Station Freedom, the United States has moved steadily into larger and more ambitious programs of ever-increasing complexity. Each has been a logical extension of what came before. Each built on past experience.

The rationale for exploring and settling space mirrors the spirit that has compelled explorers through the ages: the human urge to expand the frontiers of knowledge and understanding and the frontiers where humans live and work. That is the basic reason people explore on land, sea, and in space, and has been since humans first walked on Earth.

The imperative to explore is embedded in our history, our traditions, and our national character. Throughout the drama of American history, our forefathers, with resourcefulness, audacity, and ingenuity, explored a seemingly limitless continent, using the wealth of natural resources to sustain them along the way. Today, men and women have explored nearly every corner of the planet, even to the bleak center of remote Antarctica. Now, in the late 20th Century and the early 21st, men and women are setting their sights on the Moon and Mars, as the exploration imperative propels us toward new discoveries.

Reproduced from the Report of the 90-Day Study on Human Exploration of the Moon and Mars, by U.S. National Aeronautics and Space Administration. Washington, The Administration, 1989. p. 1-1 - 1-9.

The Human Exploration Initiative

To enrich the human spirit, to contribute to national pride and international prestige, to inspire America's youth, to unlock the secrets of the universe, and to strengthen our Nation's technological foundation: human exploration of the Moon and Mars will fulfill all these aspirations and more. This document provides a framework within which various approaches to meeting these national goals may be analyzed. The basic mission sequence is clear: begin with Space Station Freedom in the 1990s, return to the Moon to stay early in the next century, and then journey on to Mars. An end-to-end strategy for implementing the mission begins with robotic exploration to determine and characterize the lunar and martian environments in which spacecraft and crew must function. The next step is to build a permanent outpost on the Moon to support human presence for science and exploration. In addition to the benefits to be gained from lunar exploration for its own sake, the lunar outpost serves a vital parallel purpose. Just a 3-day journey from Earth, the Moon provides the ideal location to develop the systems and experience to prepare for the next step of the Initiative: an outpost on Mars.

The mission objectives dictate a common profile for both outposts, beginning with the launch of crew and cargo from Earth, with the crew on the Space Shuttle and most of the cargo on new heavy lift launch vehicles. The destination is Space Station Freedom, where vehicles are assembled, fueled, and serviced for the next stage of the journey. Concepts have been developed for transfer vehicles that carry the crew and cargo from Freedom and to and from lunar and Mars orbit and for excursion vehicles that meet the crew and cargo in orbit and bring them to the surfaces of the Moon and Mars.

Specialized concepts have also been developed for the systems that support human explorers as they live and work on the Moon and Mars. A combined habitation and laboratory module provides a comfortable environment for living, recreation, and scientific research. Power system concepts ranging from photovoltaic to nuclear were developed to support increasing levels of activity and scientific research. For travel across planetary surfaces, various rovers will be used, some that crew members drive, and others that operate robotically. In situ resource utilization, which would increase outpost independence from planet Earth, may also be supported at the outposts. And finally, launch and landing sites have been designed for the vehicles that bring crew members to planetary surfaces and take them on the first leg of their journey home.

Reference Approaches

The Human Exploration Initiative provides a framework within which various elements of and approaches to human exploration of the Moon and Mars can be examined. In order to provide the data necessary to make these types of assessments, several reference approaches have been selected to determine which parameters drive such things as cost, schedule, complexity, and program risk. Five reference approaches were analyzed, each of which is characterized by a particular emphasis: (1) balance and speed; (2) the earliest possible landing on Mars; (3) reduced logistics from Earth; (4) schedule adapted to Space Station Freedom; and (5) reduced scale. The information generated through this process can be used as a data base for determining the appropriate scope, schedule, and ultimate approach to be used in implementing the program. The data generated by this process are intended to capture the range of possibilities based on our technical understanding today, and, consequently, can be used to develop implementation approaches for any number of options.

Infrastructure

The existing NASA infrastructure of Earth-to-orbit transportation systems, Space Station Freedom, and telecommunications, navigation, and information management systems will be an integral element of any human exploration program. In parallel with the development of the Initiative, current and projected capabilities in these areas were assessed to determine where augmentation might be necessary.

In the area of Earth-to-orbit transportation, the Nation's current mixed fleet of Space Shuttles and expendable launch vehicles clearly requires enhancement. The Space Shuttle will be used to carry the crew to Space Station Freedom, but the massive cargo flights necessary to support extraterrestrial human exploration mandate launch vehicles with much greater lift capacity: approximately 60 metric tons for the lunar outpost, and about 140 metric tons for the Mars outpost. (The current Shuttle has a capability of 17.3 metric tons.) Various concepts for vehicles to accommodate these requirements range from Shuttle-derived vehicles to versions of the planned Advanced Launch System. New ground facilities will also be required to support the new vehicles.

Space Station Freedom will serve a vital role in human exploration: it will provide the essential scientific and technological foundation for later human missions to the planets, and it will serve as a transportation node for the missions of the Initiative. Space Station Freedom will serve as an on-orbit laboratory for conducting research and developing technology that is required by the

Initiative. Freedom is the ideal location for such studies and demonstrations because no terrestrial laboratory can adequately simulate the characteristics of the space environment. Research will determine acceptable long-term microgravity countermeasures and obtain data for the design of self-sufficient life support systems. Freedom can advance technology by serving as a test-bed for new lunar and Mars system developments. Further, the hardware, software, and other technologies used to assemble and operate Freedom can be applied to exploration vehicles and systems.

A significant feature of Space Station Freedom's design is its capability to add pressurized laboratory and habitation modules, power generation equipment, truss extensions, and specialized facilities. This capacity allows Freedom to evolve gracefully as its requirements as a research facility and transportation node increase over the lifetime of the Initiative. Freedom will evolve sequentially through four configurations to support four Human Exploration Initiative milestones: the verification flight of the lunar transfer vehicle, expendable lunar transfer vehicle operations, reusable lunar transfer vehicle operations, and orbital operations in support of Mars missions.

The Human Exploration Initiative is also expected to stimulate new developments in telecommunications, navigation, and information management. These enabling support functions monitor and control mission elements, acquire telemetered data from engineering and science measurements, provide radiometric data for navigation and video data for operations and science activities, and provide a capacity to communicate, receive, distribute, and process information. These functions must be provided efficiently, with human-related reliability.

Several challenges must be met: incorporating highly unattended operations for many of the local Mars telecommunications and navigation functions, achieving a high Mars-Earth data rate, providing robust system connectivity for manned links, and providing an information management discipline, including standards, for use in transferring data between system nodes.

Meeting Human Needs in Space

Exploring the frontier has always been risky to the lives of the men and women at its edges. Now, astronauts are preparing to venture for long periods of time into environments more harsh, albeit more challenging and fascinating, than any encountered on Earth. Fundamental differences between space and Earth–the lack of gravity, inadequate atmospheres, deep cold, and radiation hazards–challenge our ability to protect, nurture, and sustain the individuals who will be the pioneers of the solar system.

Life scientists have major responsibilities under the Human Exploration Initiative: to the crew, to assure their health, productivity, and safety throughout the mission and the postflight rehabilitation period; to the mission, to provide a productive working environment; and to the scientific community, to advance knowledge and understanding of human adaptation to the space environment.

Critical areas essential to support of human exploration include protection from the radiation hazards of the space environment, of the utmost importance both for journeying to and living on other planetary bodies. Limits must be determined, and protective measures, including shielding, storm shelters, and warning systems, must be developed.

Other important health-related areas include reduced gravity countermeasures, medical care, and life support systems. The final area that must be investigated is one about which we have very little data: behavior, performance, and human factors in an extraterrestrial environment.

Science Opportunities and Strategies

A long-standing policy goal of the U.S. civil space program is "to expand knowledge of the Earth, its environment, the solar system, and the universe." The Human Exploration Initiative will significantly advance scientific knowledge as we explore the Moon and Mars and learn to use their surfaces for observatories and laboratories. The act of exploration will provide new insights into the natural history of the bodies visited and may lead to their use for practical purposes. Many diverse scientific disciplines — geology and geophysics, astronomy and astrophysics, human and plant physiology, and evolutionary biology — will be greatly enhanced. Exploring the Moon and Mars will help us in many ways to understand the past and to look into the future of our own planet, the solar system, and the universe.

Our first stop as we move outward from Space Station Freedom into the solar system is the Moon, where we can find clues about the early days of Earth. Current scientific theory holds that the Moon formed when a Mars-sized body collided with Earth. By exploring lunar origins, we may understand not only the formation of Earth, but also other mysteries of our solar system, such as the tilt of Uranus and the rotational spin of Venus. The lunar surface also contains records of cratering processes, obliterated on Earth by erosion, which may contain clues about the extinction on Earth of entire species. Such breakthroughs may lead to profound discoveries about how life, including human life, evolves. Studies of the Moon will also yield important information about its natural resources, which is a vital first step in becoming a multi-planet species.

In addition to studying the Moon itself, from the lunar surface we will look outward. The Moon is a valuable platform for studying distant stars and galaxies, the rest of the solar system, and Earth itself; its quiet, stable environment provides an excellent base for astronomy. From the Moon, we can make great strides in understanding the universe, strides that are currently impossible on Earth or using orbiting telescopes. And when men and women live there, scientists will learn about the long-term effects on humans of a low-gravity environment; this is an essential step for longer-duration stays on Mars.

We will not stop at the Moon, because the imperative to explore will lead men and women to Mars. The planet most like Earth, Mars offers many unique scientific opportunities, but perhaps the most intriguing question is whether life exists or has ever existed on Mars. Ancient river beds and channels indicate that water once flowed on Mars and that life could have formed there. Life may exist on Mars today in underground habitats where volcanic heating melts ground ice, producing a warm, wet environment protected from harsh surface conditions. Only scientists working on Mars can discover the answer to this age-old question.

Studying Mars will also help us better understand changes on Earth, both natural changes and those that are caused by the presence of our species. By understanding the fascinating geological diversity on Mars, caused by drastic global climate change, we can understand more about our own changing planet.

And exploration will not stop at the Moon and Mars. As with all pioneering ventures, the Human Exploration Initiative will open new vistas of discovery tomorrow that can only be imagined today.

Technology

Space is an infinite source of challenges. To send humans to explore it and use its resources, development must begin today of new technologies in many areas, including regenerative life support systems, aerobraking, advanced cryogenic hydrogen-oxygen engines, surface nuclear power systems, in situ resource utilization, radiation protection, and nuclear propulsion. Advancements in automation and robotics, as incorporated into these and many other technologies, will significantly increase the effectiveness of operational systems. Perhaps the most tangible benefits of the Human Exploration Initiative, these developments will inevitably have spinoff applications that may profoundly affect our everyday lives and will certainly improve our position in the increasingly technological world economy.

During the decade of exploration from the late 1960s to the late 1970s, the astronauts of Apollo and the machines of Viking began to explore the surfaces of the Moon and Mars, achievements that were made possible by revolutionary advances in technologies and aerospace engineering capabilities. Innovative technological solutions to challenging engineering problems will also be one of the hallmarks of the coming era of exploration. Each step of the march to Mars — sending robotic missions to the Moon and Mars, establishing a lunar outpost, staging initial expeditions of humans to Mars, and ultimately emplacing an outpost on Mars — will drive technological and engineering expertise to greater heights and new standards of excellence.

The Human Exploration Initiative will involve dozens of major systems and will span decades. Technology development will be a multifaceted process that tests the best scientists and engineers in the Nation, builds on the considerable base that NASA has accumulated over the years, and evolves as the Initiative progresses. As mission objectives are crystallized, system concepts developed, and applicable technologies selected for pursuit, nearer-term advanced development programs will focus on creating individual operational systems. These advanced development programs will in turn feed into the design, development, test, and evaluation programs that will produce the flight hardware and software for specific Human Exploration Initiative systems. Throughout all programmatic phases in the life of the program, engineering ingenuity and technological innovation will characterize the Initiative.

Significant technology development needs to begin as soon as possible. A balanced, focused investment in technology will make possible the levels of performance and the scope of operations envisioned. Technology development will precede and foretell the major accomplishments of exploration, leading by several years the actual missions to the Moon and Mars.

National and Institutional Impact

The Human Exploration Initiative presents our Nation with exhilarating challenges, significant opportunities, and enormous benefits into the first part of the next century and beyond.

The Human Exploration Initiative will draw heavily on NASA's personnel, facilities, and equipment. This resource base, the NASA institutional core capability, is built on 75 years of research, development, and operational experience and hundreds of unique national facilities. From the National Advisory Committee on Aeronautics to the creation of NASA in 1958 to the present, the Agency has developed an unparalleled capability in civil space research and development and aeronautics.

NASA will request a significant augmentation of civil service positions to support the Human Exploration Initiative. These positions will provide the necessary technical expertise, program management, and administrative support to meet the objectives of the Initiative. The augmentation will also enhance the in-house work force, providing a solid balance between in-house and contracted efforts.

The Human Exploration Initiative will challenge current management systems. It presents a unique opportunity to explore and test streamlined administrative and management processes for directing long-term, complex, highly visible U.S. programs having significant international implications. The lessons learned may yield invaluable guidance transferable to other important U.S. programs.

Three areas will offer the greatest opportunity to realize significant efficiencies and enhanced effectiveness: the acquisition system, the budget process, and human resource management systems. NASA has already begun to address these areas internally, but some elements are outside NASA's control and will require active support from other Government quarters.

Potential international participation in the Human Exploration Initiative is the subject of a separate policy analysis being conducted under the direction of the National Space Council. That analysis will assess international capabilities, opportunities, issues, and options related specifically to the Human Exploration Initiative. This document complements that activity by pulling together information based on NASA's extensive experience in conducting space missions with foreign partners.

With the growing capabilities and increasing number of other spacefaring nations, the environment for international participation is considerably different than it has been in the past. The Human Exploration Initiative offers the potential for a variety of cooperative approaches with a number of potential partners. Different models may be appropriate for cooperation with different nations or for different phases of the Initiative. The National Space Council will consider these and other factors in assessing the feasibility of further international participation.

International cooperation and the use of the Initiative to serve important foreign policy goals are only two of its many benefits. The Initiative will also stimulate interest in science and engineering education, strengthen our national technological capabilities, offer a wealth of new scientific knowledge, and serve as a source of national pride.

NASA contributes to the Nation's base of technology through the transfer of research knowledge into the public and private sectors. The application and reapplication of this knowledge has a multiplicative effect, in which the general increase of efficiency and wealth from the advanced knowledge spreads throughout society. The Human Exploration Initiative will expand this contribution as advanced technologies are developed.

Another increasingly important benefit is the stimulus that the Human Exploration Initiative can provide to education. To help ensure that the Nation has an adequate, continuing supply of scientists, engineers, and other technical personnel to successfully implement the President's Human Exploration Initiative, an aggressive and targeted educational action plan is needed. To contribute to solving the predicted shortage of scientists and engineers, NASA will redirect and enhance its existing aerospace education program into a new, comprehensive, educational initiative entitled "Space Literacy for the 21st Century."

The educational frontiers opened by space exploration will captivate new generations of students, the scientific and technical work force of the future. This phenomenon, combined with the other scientific and political benefits of the Initiative, will open new horizons of achievement and will serve as a source of national pride. Taken together, the benefits of the Initiative — scientific understanding, technological advancement, motivation of our Nation's youth, and more — will significantly strengthen our position in the global community.

Some day it may be said that the residents of Earth had to leave their planet in order to find it. Indeed, from space, humans first got to see their own planet, floating in blackness above the barren moonscape like a blue and white marble. Perhaps more than anything else, this view of Earth dramatized our planet's uniqueness, and its fragility.

The last half of the 20th Century and the first half of the 21st Century will almost certainly be remembered as the era when men and women broke the bonds that bound them to Earth and set forth on a journey into space.

That journey will, in time, extend human presence throughout the solar system. Historians will note that the Moon became a familiar place to Earthlings very early in that period. They returned there to follow in the bootprints of Armstrong, Aldrin, and their Apollo colleagues, to establish an outpost for further exploration and expansion of human activities, to Mars and beyond.

Historians will further note that the journey to expand human presence into the solar system began in earnest on July 20, 1989, the 20th anniversary of the Apollo 11 lunar landing when President George Bush announced his proposal for a long-range continuing commitment to a bold program of human exploration of the solar system.

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CRS Issue Brief

Space Stations

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Space Stations

SUMMARY

President Reagan's 1984 decision directing NASA to build a permanently occupied space station as its next major space program has met with mixed responses. Members of the space science community are worried that a commitment of the funding and personnel needed to build and operate a space station will drain resources from their programs. The doubling of NASA's estimated costs for the space station in early 1987 added fuel to this debate. Others feel that the space station is a critical step for realizing President Bush's stated goals of returning humans to the Moon and then going on to Mars (the Human Exploration Initiative), as well as for performing research that could lead to profitable space industries (such as manufacturing).

There also is concern that the United States is losing its leadership in space to the Soviet Union. The Soviets are currently operating their seventh successful space station and have had people remain on board space stations for one year (compared with 84 days for the longest U.S. flight in 1973-1974; the space shuttle can only remain in orbit for 7-10 days at a time). Whether the perception of a Soviet lead in this area will ultimately influence U.S. policy remains to be seen.

Perhaps of greater concern in the long term is potential competition from Europe and Japan. Both are involved in the U.S.-led space station, but could have an autonomous capability to place crews in orbit early in the next century. If space-based products become profitable, countries able to research and produce in space, and to service space facilities, could have a significant advantage. Thus the space station could be an important factor in maintaining U.S. competitiveness in new areas. Today, however, it is virtually impossible to know what those products or services might be.

Potential use of the space station by the Department of Defense (DOD) has also become a controversial issue. Some Members of Congress want to prohibit all military activities on the space station, while others want DOD to have no restrictions on use. Still others want to permit some activities, such as research and development, but prohibit testing and/or deployment of weapons.

The essential question regarding the space station program is whether it is a worthwhile investment of resources. Supporters argue that the space station will not get cheaper with time and, if the country wants to move forward in space programs, the space station is "the next logical step" and must be built now. Opponents assert that the $19 billion (real-year dollars) for research and development alone through the mid-1990s could be better spent on automated space activities, or in non-space areas. Through FY1990, Congress has appropriated $3.89 billion for the program. NASA has requested $2.6 billion for FY1991.

ISSUE DEFINITION

The United States has decided to build an Earth-orbiting permanently occupied space station. NASA terms it "the next logical step," but the justification of the station is still being questioned, especially since the anticipated cost will be much higher than originally expected. One factor in deciding the pace and timing of the space station program is what other countries are doing. The Soviet Union has been launching space stations since 1971, and currently has two in orbit. Europe, Japan, and Canada are now planning to participate with NASA in building the U.S.-led space station, but if the schedule slips significantly or they become sufficiently dissatisfied with cooperating with the United States, they might decide to proceed separately. Thus the space station is seen as important, not only for conducting scientific research in orbit and serving as an operations center for achieving goals such as returning humans to the Moon and going on to Mars, but also for maintaining U.S. leadership in space.

BACKGROUND AND ANALYSIS

Introduction

Skylab

NASA has launched one space station, *Skylab*, to which three crews were sent in 1973-74, staying 28, 59, and 84 days, respectively. Over 100 experiments were conducted, resulting in significant scientific information in the areas of astronomy, space physics, materials processing in space (MPS), and biomedical research. *Skylab* was not designed to be permanently occupied, and reentered the Earth's atmosphere in July 1979, disintegrating over Australia and the Indian Ocean.

1969 Post-Apollo Reports

Possibilities for a permanent space station were studied seriously as part of U.S. space goals in the post-Apollo era. At the request of President Nixon in 1969, a Space Task Group (STG) consisting of the Secretary of the Air Force, the NASA Administrator, the President's Science Advisor and the Vice President was set up to outline the future direction of the United States space program. The STG report did not choose a single goal for the U.S. space program, but rather laid out a variety of options. It soon become clear that for the immediate future, NASA's hopes would lie with a permanent space station and a space transportation system to access it. By this time, it was also clear that NASA's budget would be more constrained than in previous years and NASA would have to choose between those two programs. The choice was made to develop the space transportation system first -- the space shuttle -- and then the space station. The space shuttle made its first flight in 1981, and a year later was declared operational. NASA was then ready to initiate the space station program.

1984 Reagan Administration's Space Station Initiative

In his Jan. 25, 1984, State of the Union address, President Reagan directed NASA to develop a permanently occupied space station within a decade. He said "we can follow our dreams to distant stars, living and working in space for peaceful economic and scientific gain." He further commented that such a program would permit "quantum leaps in our research in science, communications, and in metals and lifesaving medicines which can be manufactured only in space." He also said that NASA would invite other countries to participate in the project.

1989 Bush Administration's Space Program Goals

On July 20, 1989, the 20th anniversary of the first landing on the Moon, President Bush gave a major space policy address in which he reiterated his support for the space station as the cornerstone of a long-range civilian space program involving a study of Earth (called Mission to Planet Earth), and eventually leading to bases on the Moon and Mars "in the 21st Century." No timetable was given for the Moon and Mars parts of the program, but the President stated that he hoped the country would be able to celebrate the 30th anniversary of the Moon landing (in 1999) by having space station *Freedom* operational.

Space Station *Freedom*

The space station is a cooperative venture between the United States, Japan, Canada, and nine of the 13 members of the European Space Agency (ESA). In July 1988, President Reagan, in consultation with the other partners, chose the name *Freedom* for the space station.

After several years of study and preliminary design, the space station program entered the detailed design and development (or Phase C/D) stage on Dec. 1, 1987, when NASA awarded contracts for each of the four work packages that together comprise the program: Work Package 1 (managed by NASA's Marshall Space Flight Center, AL) for the space station habitation and laboratory modules went to Boeing; Work Package 2 (Johnson Space Center, TX) for space station assembly and truss structure went to McDonnell Douglas; Work Package 3 (Goddard Space Flight Center, MD) for platforms and customer servicing equipment was awarded to General Electric; and Work Package 4 (Lewis Research Center, OH) for power systems went to Rockwell International.

NASA currently plans the "first element launch" for the space station in early 1995, with a shuttle-tended capability in April 1996, a permanently occupied capability in July 1997, and assembly complete in August 1999. Through FY1990, Congress has appropriated $3.89 billion for the program; NASA has requested $2.6 billion for FY1991.

Space Station Design

Since 1984, when President Reagan formally initiated the space station program, the design of the space station has been redefined and rescoped, and its assembly plans rephased, several times. Initially, the space station would have consisted of three different objects: the occupied base (which most people thought of as "the" space station); an automated platform near the occupied base for activities such as astronomical observations, called a "co-orbiting platform"; and an automated platform in an orbit around Earth's poles (a "polar platform") for observations of the Earth. All would have had similar components, hence the inclusion of all three in the space station program.

Today, the U.S. portion of the Space Station *Freedom* program is only the occupied base. The co-orbiting platform has been indefinitely postponed, and the polar platform has been shifted out of the space station program and into the activities of the Office of Space Science and Applications (OSSA), since its use is for earth observations (an OSSA responsibility) and because engineers realized there would be little if any component commonality between the polar platform and the occupied base. Other countries participating in the space station program (Europe and Japan) are building their own co-orbiting and polar platforms, however.

As currently configured, Space Station *Freedom* will be a permanently occupied space station in a 500-kilometer orbit inclined at 28.5 degrees. When fully operational in 1999, it will be occupied by crews of eight working on a 3- to 6-month rotation. Crews will live and work in four habitable modules, two provided by the United States, one by Europe, and one by Japan. The Japanese module will also have a section exposed to the space environment for certain scientific instruments. Canada is providing a Mobile Servicing System (MSS) for assembling and maintaining the space station servicing attached payloads, transportation on the space station itself, and deploying and retrieving payloads. The United States is building a Flight Telerobotic Servicer (FTS) for working in the vicinity of the space station, too. The modules, MSS and FTS, will all be attached to a lattice-work truss structure that also accommodates scientific instruments and solar arrays producing 75 kilowatts of electrical power. The space station will be transported to Earth orbit in pieces by the space shuttle and assembled there by astronauts and robotic equipment (the MSS and FTS).

Major design reviews were performed in 1986 (following the space shuttle *Challenger* tragedy), 1987 (due to rising costs), and 1989 (due to rising costs and lower than expected funding). The National Academy of Sciences' National Research Council (NRC) reviewed the 1987 design changes, which adopted a "phased development approach" in which some aspects of the program were deferred to a "Phase 2" program. No funding has been requested for Phase 2, which would include the U.S. co-orbiting platform and more of the lattice-work truss on which to mount scientific experiments. At the time of the 1987 review, NASA announced that the anticipated cost of the program had almost doubled from $8 billion to $14.5 billion dollars (FY1984 dollars), not including Phase 2.

In 1989, NASA chose to rephase the construction schedule for the space station, stretching it out by 2 years. In the near term, there will be several impacts of the rephasing, including reduced crew size and electrical power availability. Among the most significant changes are long delays in the scheduled launch dates of the European and Japanese modules.

NASA developed the plan for these changes during the summer of 1989 in a special exercise at one of NASA's field centers (Langley Research Center in Virginia). The activity was performed without consulting the international partners, creating considerable displeasure on their part, since the intergovernmental agreements that govern participation in the program establish a process whereby all partners are supposed to be included in such discussions. At hearings before the House Science, Space and Technology Committee on Jan. 30, 1990, the Director General of the European Space Agency, representatives of the French, German, and Italian space agencies, and the executive director of Japan's National Space Development Agency, expressed their dissatisfaction with NASA on this point, though all expressed confidence in a favorable resolution. In fact, the ESA director general announced the receipt of a letter from NASA suggesting other options for the timing of the launch of the European module, which could move the launch date forward by a year.

Thus the phasing of the construction sequence for the station apparently is still under review, although NASA is maintaining its commitment to launch the first element in 1995. NASA states that it will actually begin fabrication of the space station in 1990, although this fabrication is of test elements, not actual hardware that will be part of the station itself. Fabrication of actual space station hardware ("flight hardware") will not occur until after the space station design has passed the Preliminary Design Review (which has been postponed from the summer of 1990 to December 1990) and the Critical Design Review. Such construction is currently expected to begin in 1993.

Space Station Cost and Funding

Cost. The space station envisioned by NASA for initial operation in the early 1990s was originally estimated to cost $8 billion in FY1984 dollars. That estimate did not include the cost of transporting station components during its construction, the costs of scientific or commercial payloads, future expansion costs, or operational costs. NASA expected operation of the space station to cost approximately $500 million per year.

The revised plan submitted in April 1987 doubled that estimate. In April 1989, NASA estimated the costs for Phase 1 as follows (real year dollars assuming approximately 5% inflation through 1996): $19 billion for research and development; $24 billion if other costs are included (the Flight Telerobotic Servicer, ground facilities associated the program, transition definition, an orbital debris radar, operations through the end of 1996, and previous studies). Neither estimate includes transportation costs to put the space station in orbit or resupply it, operations costs past 1996, or a crew return vehicle (see **Issues** section).

FY1985 and Prior-Year Funding. For FY1985, NASA requested and received $150 million for initiating the space station program. This was the first year that the space station was a line item in NASA's budget, although funding had been provided in both FY1983 ($4 million) and FY1984 ($14 million) for space station studies. In addition, NASA spent approximately $29 million in both FY1983 and FY1984 for generic technology development within its Office of Aeronautics and Space Technology that could be considered related to a space station.

FY1986-88 Funding. NASA requested $230 million for the space station in FY1986; Congress appropriated $205 million. For FY1987, the request was $410 million, and Congress appropriated that amount. In FY1988, NASA requested $767 million, but Congress appropriated only $425 million. NASA has said that the cut in funding ultimately will add $1.4 billion to the cost of the program.

FY1989 Funding and 3-Year Authorization. NASA requested $967 million for the space station program, and Congress appropriated $900 million. Funding for the program was quite controversial during deliberations over the FY1989 budget, and the final appropriation figure was a compromise between $902 million approved by the House and $200 million approved by the Senate.

In the FY1989 NASA authorization bill (P.L. 100-685), Congress approved an Administration request for a 3-year authorization for the space station program. The authorization amounts were $900 million for FY1989, $2.13 billion for FY1990, and $2.9 billion for FY1991.

FY1990 Funding. NASA requested $2.05 billion for the space station program, slightly less than the pre-authorized amount. Congress appropriated $1.8 billion, but with the impact of the Budget Reconciliation Act, it is expected that the total available for this program will be $1.75 billion. No NASA authorization bill was passed in the first session of the 101st Congress, although both House and Senate authorizing committees had recommended full funding for the space station in their respective bills (see **Legislation**).

FY1991 Request. NASA is requesting $2.431 billion for space station R&D for FY1991. The total request is $2.627 billion if facilities and program management are included.

International Involvement

Canada, Japan, and nine of the 13 members of the European Space Agency (ESA) are participating with NASA in building the space station. (The nine European countries are: Belgium, Denmark, France, Federal Republic of Germany, Italy, the Netherlands, Norway, Spain, and the United Kingdom.) All the partners signed an Intergovernmental Agreement (IGA) on Sept. 29, 1988, which sets forth the basic parameters of the space station agreement, including provisions for management of the station. Each partner also signed a memorandum of understanding (MOU) spelling out specific responsibilities. Canada and ESA signed their MOUs at the same time as the IGA; Japan signed its MOU on Mar. 14, 1989. Each partner's government must ratify the agreements. In addition, letters of agreement were exchanged to deal with special issues, in particular the potential military uses of the space station.

Canada's contribution to the space station is the Mobile Servicing System (MSS), designed to assemble and maintain the space station, service attached payloads, and retrieve/repair satellites. The MSS is being built with technology Canada used for the Remote Manipulator System (the "arm") it built for the U.S. space shuttle. Japan is building a laboratory module, called the Japanese Experiment Module (JEM); part of the module will be pressurized and another part will be exposed to space (for certain experiments requiring those conditions). ESA is building a pressurized laboratory module called *Columbus*, and also is planning a co-orbiting platform, called the Man-Tended Free Flyer (MTFF), and a polar platform. In total, the international partners are expected to spend $8 billion (FY1989 dollars) on their contributions to the program.

Potential military uses of the space station complicated negotiations with the international partners. An exchange of letters between the United States and each of the partners clarified that each partner shall determine whether a contemplated use of its portion of the station is for peaceful purposes. Whether this language is sufficient to win approval from the various governments will not be known until the agreements are put forward for ratification in each country. (Norway and Denmark were the only two governments to have ratified the agreement by October 1989.)

As discussed under the section on Space Station Design, the international partners have expressed concern to Congress about NASA's excluding them from the initial discussion on rephasing space station construction. The partners have expressed confidence, however, that these matters can be resolved.

DOD Use of the Space Station

When the space station program was approved in 1984, the Department of Defense concluded that the military had no specific requirements for a space station. In December 1986, however, DOD expressed concern that the agreements NASA was negotiating with its international space station partners might restrict its use of the station in the future. Space station negotiations were put on hold pending clarification of DOD's concerns. In February 1987, negotiations resumed, with the partners expressing some concern over the proposed U.S. wording regarding use of the space station for national security purposes. NASA emphasizes that the space station is civilian and it simply wants to assure that the space station can be used for national security purposes consistent with the U.S. commitment to peaceful uses of space.

The House debated this issue in hearings and during floor consideration of the FY1988 NASA authorization bill. Ultimately, the House adopted Senate language stating that the space station can only be used in accordance with U.S. treaty obligations. (The United States is signatory to four treaties specifically concerning space activities, as well as others (such as the ABM treaty) that include provisions about space activities.) In response to legislative language in the FY1988 DOD authorization bill, DOD submitted a report to the House and Senate Committees on Armed Services on Mar. 1, 1988, concerning its potential use of the space station. DOD stated that it regards the space station as "dedicated primarily to civil space activities, but available to the DOD in accordance with national priorities and international commitments." The report concluded that today "We have no current requirements for major payloads which would use or uniquely require the space station," but that in the future a space station might serve as an observational base or a logistics base for activities such as repairing spacecraft. The agency stressed that "We do not plan to conduct tests of weapons systems using the Space Station, but may consider the use of the Station for certain test and development activities."

Soviet Space Station Activities

Following their failure to develop a launch vehicle capable of placing cosmonauts on the Moon, the Soviets turned their attention to Earth orbit and launched the first space station, *Salyut 1*, in 1971. Since then, five more Salyuts and a space station called *Mir* have been successfully orbited. Two others failed before they could be occupied.

A wide range of experiments have been conducted aboard the successive space stations including research in medicine, Earth resources, materials processing, astronomy, and closed-cycle life support systems.

Today, the Soviets have two space stations in orbit, *Salyut* 7 (launched in 1982), and *Mir (Peace)*, launched in 1986. Mir is the first of a new generation of Soviet space stations that has several improvements. First, it has six docking ports instead of two, permitting the Soviets to conduct a versatile research program. There is one port on each end of the station, and four around the circumference of the station near the forward port. Specialized modules can be docked with *Mir* to perform specific tasks such as materials processing research, astronomical research, or remote sensing of the Earth and oceans. Previously, equipment to conduct such research had to be incorporated inside the space station itself, limiting the size and amount of equipment. The new design provides a central core, the same size as the Salyut space stations, that can be devoted to crew accommodations (there are now private sleeping compartments, for example), and the scientific equipment is in the modules, which can be changed as research directions change. Second, *Mir* has more and better computers, relieving the crew of many routine operations. Third, the crew can communicate with ground control through a relay satellite, permitting greater communication opportunities.

In 1986, one crew docked with *Mir*, and later transferred over to the *Salyut 7* space station using their Soyuz ferry craft. (The Soyuz spacecraft has been used since 1967 for taking crews to orbit.) After 50 days on *Salyut 7*, they "taxied" back to *Mir* for another 3 weeks, and then returned home. *Salyut 7* has been mothballed in orbit since.

A new crew was launched to *Mir* in February 1987, and one of its members (Romanenko) set a new duration record of 326 days. His companion (Laveikin) had to be replaced in July because of medical problems, demonstrating the flexibility of the Soviet space program to adapt to changing circumstances. An astrophysics module, *Kvant*, docked with *Mir* after the crew went out on a spacewalk to remove an obstruction from the docking port. The crew conducted two more spacewalks to add more solar panels for generating electricity for the station.

Romanenko and his new co-worker, Aleksandrov, returned to Earth on Dec. 29, 1987, after being replaced by a new pair of cosmonauts, Titov and Manarov. They were launched on December 21 with a third cosmonaut, Levchenko, who returned with Romanenko and Aleksandrov. Levchenko's flight was related to the development of the Soviet space shuttle and after he returned to Earth, he was taken directly to an airport to fly an airplane to see if spaceflight had impaired his piloting abilities. (Levchenko died from a brain tumor in the summer of 1988; the condition was not thought to be related to his spaceflight.)

Titov and Manarov were aboard *Mir* throughout 1988, finally returning on Dec. 21 after a record 366 days in space. In June, they had been visited by a crew that included a Bulgarian, and in August, another visiting crew, composed of a Soviet pilot, a Soviet physician, and an Afghan researcher, arrived. The physician, Polyakov, remained onboard the space station with Titov and Manarov, while the Soviet pilot and Afghan returned to Earth. During that return, problems were encountered with the spacecraft that "stranded" the two in orbit for a day, after which they made a successful landing.

A third visiting crew was launched to *Mir* on Nov. 26, 1988, composed of two Soviets, Volkov and Krikalev, and a Frenchman, Jean-Loup Chretien. Chretien remained on the space station for 3 weeks (usually cosmonauts from other countries remain for only 1 week) and performed a spacewalk with Volkov, becoming the first non-American, non-Soviet to make a spacewalk. He returned to Earth on Dec. 21 with Titov and Manarov. The three also encountered problems with their spacecraft which delayed the landing by 3 hours.

Polyakov, the physician, remained on the space station with Volkov and Krikalev. The Soviets said that this new team would not attempt to set a new duration record, and would return to Earth in April 1989. They also said a replacement crew would be launched on April 19, but on April 11-12 they announced that the space station would be left unoccupied for several months because of delays in completing the next two modules (the airlock module that will make it easier for the cosmonauts to conduct spacewalks, and the materials processing module) scheduled to be attached to *Mir*. Since the scientific experiments are on the modules, without them there would be little for the crew to do other than continue observations with the *Kvant* astrophysics module. The Volkov-Krikalev-Polyakov crew returned to Earth on April 27.

Some Western analysts attributed the decision to budget problems, and a week after announcing that the decision had been based on the module delays, the Soviets added that budgetary decisions had been a factor. Still, it seems that budgetary influences would have been secondary, since the blossoming debate in the Soviet Union over the wisdom of space program spending is very new and it seems too early to expect programmatic changes because of that debate. It is more likely that budgetary decisions would affect recently approved and new programs, rather than existing programs that are already paid for in large part. A new crew was launched to *Mir* in September, and the airlock module (*Kvant 2*) was supposed to be launched the next month. Due to technical problems, the launch was delayed until Nov. 26, 1989. *Kvant 2* docked with *Mir* in December 1989.

The Soviets are developing their own space shuttle, but it has flown only once, and it did not carry a crew. For the indefinite future, they will continue to use Soyuz TM vehicles to take crews to and from space. The Soviets also have a new heavy lift launch vehicle, Energiya, that will launch their shuttle and could be used to launch large space station components to orbit.

The Soviets, by virtue of their long-endurance flights, have considerable experience coping with the deleterious effects of weightlessness on the human body. The United States has only the *Skylab* experience. The Soviet Union does share its biomedical space data with NASA, and it should be of benefit in planning work, rest and exercise schedules for space station operations. They also have accumulated considerable experience in materials processing research, and one of the modules that will dock with *Mir* will be devoted entirely to this field.

Issues For Congressional Consideration

Uses and Need for the Space Station

The space station was originally conceived as a facility that would be of use to many different segments of the space community: an operations base for servicing spacecraft already in Earth orbit or assembling spacecraft to go to the Moon, Mars or elsewhere in the solar system; a laboratory for performing experiments on humans to better understand their adaptation to the space environment in preparation for trips to Mars; a laboratory for experiments related to materials processing in the near-zero gravity of space (growing purer crystals that might ultimately become the computer chips of the future, or manufacturing purer vaccines), a platform on which to mount instruments that could either look down at the Earth or out into the universe; and a technology driver, with the development of robotic systems such as the Flight Telerobotic Servicer and the use of new electrical power generation technologies such as solar dynamic power.

Because of rising costs and constrained funding, the space station has been descoped over the years, and some observers question exactly what the space station is being designed for now. With the announcement by President Bush of the goal of returning humans to the Moon and then going on to Mars in the 21st Century (the Human Exploration Initiative), the role of the space station as an operations base seems to be expanding. In this context, the station would also serve as a laboratory for life sciences research on human adaptation to long-duration spaceflight.

At the same time, the role of the space station as a laboratory for materials processing in space (MPS) research is being questioned. The space station is designed to provide 75 kw of electrical power, and, originally, half of that amount would be used for "housekeeping" functions (the routine operations of the station) and half for experiments, including MPS. The housekeeping power requirements are growing, however, meaning that less will be available to experimenters (the option of developing solar dynamic power has been deferred because of cost and time considerations). Critics of the space station have contended for years that the occupied base is a poor place on which to conduct MPS experiments in any case, because the crew produces an environment that complicates the experiments (by creating vibrations through hitting against walls, for example). Thus, they argue that MPS experiments should be conducted on separate platforms (co-orbiting platforms) tended by space shuttle crews.

The use of the station for astronomical and earth observing purposes has diminished as the amount of truss structure for attaching these types of payloads decreased during down-scaling of the station in 1987. The 1989 decision to divorce the polar platform from the space station also lessens the relationship of the space station program to earth observations.

Critics of the program argue, therefore, that the space station is becoming simply a part of President Bush's Human Exploration Initiative (HEI) and has little other justification. The price, they argue, is too high for such a narrow role, and that if HEI is the driver for the station today, it should be redesigned specifically for that purpose, possibly resulting in a less expensive station. MPS experiments could be conducted on shuttle-tended platforms, perhaps provided by the commercial sector (see CRS Issue Brief 88053, *Space Facilities: the ISF/CDSF/Space Station Controversy*.) Advocates argue that ultimately the space station will have its original configuration and will be useful for all the purposes for which it was originally intended. Starting over again in designing the station could threaten political support for the station, for which $3.9 billion already has been appropriated. The HEI itself is controversial, since many scientists believe that automated spacecraft, not people, should be used to explore the solar system. Thus, if the justification for the space station were only the HEI, the space station could lose scientific support as well. (For more information on the HEI, see Issue Brief 87018, *Space Policy*.)

Six years after the program was initiated, the space station is still embroiled in controversy over its basic purpose. As funding requests for the program continue to increase, Congress undoubtedly will examine the program closely to determine whether it is a wise investment of taxpayer dollars.

Crew Return Vehicle

An issue of growing importance is whether the space station should be equipped with a Crew Emergency Return Vehicle (CERV) that could return astronauts to Earth in an emergency. Originally, plans called only for a "safe haven" on the space station to provide safety for the crew in the event of depressurization or increased radiation hazards from solar flares, for example, but would not help in a medical emergency (such as an attack of appendicitis). A CERV could also give the crew a way to return to Earth if the shuttle was grounded again, as it was after the *Challenger* tragedy. NASA intends to have what it calls an "assured crew return capability" from the space station and is in the process of studying various concepts, although it is not included in the costs for the space station program.

The National Research Council's Committee on the Space Station stated in 1987 that CERV is a "mandatory requirement" for the space station, and NASA's Aerospace Safety Advisory Panel has also strongly recommended its inclusion. Opponents of CERV argue that it would be too expensive, and astronauts should be willing to accept the risks involved in spaceflight. Others are persuaded that an emergency rescue capability is needed, but worry that NASA will "gold plate" it, making it unacceptably expensive, and want to constrain NASA's ideas. On Oct. 3, 1989, NASA released a request for proposals (RFP) for what are called Phase A prime and Phase B studies of an assured return vehicle. NASA expects to select two contractors who will validate requirements and mission needs, and continue conceptual definition of such a vehicle. The Phase A prime work is expected to be completed in FY1990; the Phase B work is contingent upon availability of funding. Congress reduced funding by $14 million for the Phase B studies in the VA-HUD-Independent Agencies appropriations bill for FY1990, while increasing by $1 million funding for Phase A.

Although no design has been chosen for CERV, cost estimates range from $750 million to $1.5 billion. Among the options are: having a space shuttle ready on a launch pad at all times; keeping a shuttle docked at the space station at all times; building a new launch/return capability using expendable launch vehicles (ELVs), like the Titan, instead of the shuttle, or using ELVs and a spacecraft based on an old design, like Apollo.

The Soviets deal with potential emergencies by always having a Soyuz spacecraft docked to their space station when a crew is aboard. The benefit of this approach was demonstrated in 1985 when a mission had to be terminated early because the commander, Vasyutin, became seriously ill. The Soviets have said only that he developed an "inflammation," but he was so ill that his duties as commander had to be assumed by the second in command and the crew returned to Earth in a matter of days. (Some Western analysts think that another medical difficulty shortened a Soviet space station mission in 1982, but this has not been confirmed by the Soviets. In 1987, a cosmonaut was returned to Earth early because of heart irregularities, but it was not a medical emergency.)

Space Leadership

A continuing issue is whether it is important for the United States to be preeminent in space activities. This theme has played a role in many space policy decisions throughout the space age, with the answer usually an emphatic yes.

Space has long since ceased to be the concern of only the United States and the Soviet Union. The European Space Agency, Japan, China, India, and Israel also have their own capabilities to launch satellites today, and the ESA and Japanese programs are especially vigorous. Thus, maintaining leadership no longer is a contest between the United States and Soviet Union, but with other countries as well. For example, ESA clearly wants autonomy in space at some time in the future, and plans to build a reusable spacecraft for carrying people into orbit (called *Hermes*), so it is a real possibility that by the late 1990s, Europe will no longer be reliant on other countries to take people into orbit.

The question now is whether it is still important for the U.S. to lead in space overall, and if it must lead in all areas. Future decisions on U.S. space policy and programs could be impacted significantly by the answer. In his space policy address on July 20, 1989, President Bush stated that it is America's destiny to lead in space, and his goals -- space station *Freedom* and eventual bases on the Moon and Mars -- would establish the United States as the preeminent spacefaring nation.

LEGISLATION

P.L. 101-144, H.R. 2916

Department of Veterans Affairs and Housing and Urban Development and Independent Agencies Appropriations Act for FY1990 (includes NASA). Introduced July 17, 1989; reported from House Committee on Appropriations (H.Rept. 101-150). Passed House July 20. Amendment to cut the space station program by $714 million and transfer the money to other programs was defeated (125-291). Reported from Senate Committee on Appropriations (S.Rept. 101-128) Sept. 13. Passed Senate Sept. 28. Conference report (H.Rept. 101-297) filed Oct. 18; House and Senate agreed Oct. 31. Signed into law Nov. 9, 1989.

H.R. 3729 (Roe)/ S. 916 (Gore)

National Aeronautics and Space Administration Authorization Act. Authorizes appropriations for FY1990 to NASA. Original bill H.R. 1759 introduced Apr. 10, 1989; reported from Committee on Science, Space, and Technology (H.Rept. 101-226) Aug. 31. Passed House Sept. 21; referred to Senate Committee on Commerce, Science, and Transportation Sept. 25. S. 916 introduced May 3, 1989; reported from Committee on Commerce, Science, and Transportation (S.Rept. 101-157) Oct. 3. Passed Senate, amended, Nov. 9. Clean bill H.R. 3729 introduced Nov. 19, passed House Nov. 20. Passed Senate, amended, Nov. 22, 1989.

CONGRESSIONAL HEARINGS, REPORTS, AND DOCUMENTS

U.S. Congress. House. Committee on Science, Space, and Technology. Space station cost, schedule, and performance oversight. Hearing, 100th Congress, 1st session. July 28, 1987. Washington, U.S. Govt. Print. Off., 1987. 73 p.

---- 1988 NASA authorization. Hearing, 100th Congress, 1st session. Apr. 8, 1987. Washington, U.S. Govt. Print. Off., 1987. 73 p. (Entire volume concerns space station program.)

CHRONOLOGY

07/20/89 --- President Bush made a major space policy address in which he strongly supported the space station program as a steppingstone to a long-term civilian space policy.

— The House defeated an amendment to take $714 million from the space station program and transfer it to other programs.

07/18/88 --- President Reagan named the space station *Freedom*.

12/01/87 --- Contracts awarded for space station construction (Phase C/D).

04/03/87 --- President Reagan released the new "phased approach" to building the space station and the new cost estimates for the program showing a dramatic increase.

06/00/86 --- NASA completed systems requirements review of the space station, endorsing the original design, but calling for a different assembly sequence and some modifications to increase safety for the crews.

02/20/86 --- The Soviets launched their seventh successful space station (*Mir*), a third-generation design with six docking ports.

01/28/86 --- Space Shuttle *Challenger* was destroyed during launch, killing all seven crew members. Resulting changes at NASA regarding crew safety and loading of the shuttle cargo bay on future flights, plus increased budgetary pressures, caused NASA to review space station plans.

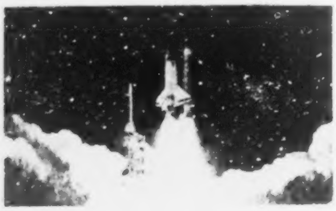
01/25/84 --- In his State of the Union address, President Reagan announced that he was directing NASA to build a space station.

05/15/73 --- The U.S. space station *Skylab* was launched into orbit.

04/19/71 --- The Soviet Union launched the first space station, *Salyut 1*.

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE COMMERCIAL DEVELOPMENT OF SPACE.

Charting the Course



U. S. Space Enterprise and Space Industrial Competitiveness

Highlights of the Report of the Commercial Programs Advisory Committee, A Subcommittee of the NASA Advisory Council

May 1989

America's Space Heritage

America's technological leadership in space has long been a symbol of national prestige, drive, intellectual vitality, and a key to international influence. The earliest U.S. space endeavors — communication satellites — have led to the creation of worldwide telephone and television services that today we take for granted. Americans alone have set foot on the moon through the advances of Apollo technology.

U.S. planetary probes have brought a new understanding of the solar system with close-up glimpses of neighboring worlds. From the vantage of space, images of coastlines, forests, and clouds have unmasked the fragility of our own planet's environment. By removing gravity from the equation, experiments aboard the Space Shuttle have revealed new possibilities for breakthroughs in many domains of science.

Looking ahead, the promise of continuous, long-term access to space will open another new era for U.S. space technology. Through Space Station Freedom and orbital platforms, space will become a new laboratory, factory, waystation to the planets — and a new basis for space enterprise.

A New Economic Frontier

As U.S. government, industry, and academic leaders answered the challenge of space exploration in the last three decades, new technology emerged and brought with it a substantial return on the space investment. Advances in computers, microelectronics, materials, electrical power, inertial systems,

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computational fluid dynamics, and thermal control have improved the lives of many Americans and expanded the U.S. industrial base.

Today, space technology is at a turning point. So far, only one truly viable industry has emerged from space exploration: satellite communication has become a multibillion-dollar industry in the United States and is a growing business for several foreign countries.

Now, new commercial opportunities for businesses and the potential for national economic growth are emerging in a wide range of markets. Business appears poised to take the lead in developing a number of new space-based enterprises. The most promising markets include:

- **Satellite applications** — not just communications, but earth observation for meteorology and resource development, navigation, geopositioning, and asset tracking.
- **Launch capabilities for transporting satellites and structures into space** — vehicles and their supporting ground facilities, maintenance, and logistics resources.
- **Facilities for working in space** — life sciences and microgravity research equipment, material processing equipment, data support, automated sample return systems, logistics, crew support, and equipment.
- **Research and development opportunities** — potential advances in health care, semiconductors, substrate materials for electronics, thin film technology, polymers, glasses, plastics, high-performance alloys, agriculture and food technology, and energy systems. The lessons learned in space about materials and research can be applied on earth, and will lead to new space-based products in the future.

Successful development of space enterprise in these and other markets will yield a number of benefits: maintaining U.S. leadership in space, contributing to economic growth and industrial competitiveness, improving the U.S. high-technology trade balance, enhancing national security, and leading to advances in such areas as health and resource management.

The Global Space Business

Thirty years ago, the sole challenger to U.S. space leadership was the Soviet Union. But with reconstruction of the industrial base in Europe and Japan, other nations have developed significant capabilities in space technology. Today, the European Space Agency, with 13 member nations, has an ambitious space program. The French Ariane launch vehicles and SPOT earth observation system have quickly gained strong positions in transportation and remote sensing markets. Other players include West Germany, Italy, the United Kingdom, Canada, as well as the Soviet Union and the People's Republic of China, with Japan and others soon to follow. America is challenged by formidable competition in all sectors of the commercial space market.

U. S. space industries face competing firms that are supported, coordinated, or to some extent owned by a foreign government. For example, Arianespace, the launch vehicle company owned by the French aerospace research establishment, European industry, and European banks, has captured more than 50 percent of the free world's launch market in only nine years. Aside from profit, the rationale for such heavy government involvement includes national objectives such as enhanced technology development, employment, and balance of trade. As a result, the U.S. space industry can no longer count on building an unchallenged market share or on being first to market.

Space and U.S. Competitiveness

Long used to a dominant position in world industrial output, the United States has lost a near monopoly in consumer electronics, semiconductors, and machine tools. By 1986, the United States had lost a high-technology balance of trade that once exceeded $25 billion

Europe and Japan are challenging the U.S. lead in pharmaceuticals and computer software. American industrial competitiveness has become a major national issue.

Space commerce can offer more than an opportunity for U.S. private enterprise; it can represent an important contribution to American competitiveness in the global market. As the NASA Advisory Council Task Force on International Relations in Space has pointed out, "a single $100 million launch contract is equivalent in economic terms to the import of 10,000 Toyotas."

What Is Needed?

The key question is this: Does the United States want to pursue leadership in the global space market? If so, U.S. space enterprise needs a supportive environment in which to overcome the barriers and risks of developing the new space business frontier. American industry must be concerned not only with the strategic moves of aggressive competitors abroad, but also with a host of challenges at home, such as national policy, government regulation, resources, access to space, technology development, and capital formation. Clear goals, strong leadership, and a close partnership between the Government and industry will be needed to take advantage of emerging space opportunities.

Although the White House, NASA, and other governmental agencies such as the Departments of Commerce, Transportation, and Defense have been supportive of commercial space development, government efforts have lacked common goals, central direction, and leadership. In the hope that a new Government-industry partnership can be forged to develop a strong commercial space sector and improved U.S. competitiveness, the Commercial Programs Advisory Committee of the NASA Advisory Council offers the following recommendations.

Key Recommendations

The following recommendations propose actions that Executive Branch leaders, government agencies, and the Congress can take to foster U.S. space enterprise and space industrial development. The Committee offers these recommendations in the belief that space enterprise offers benefits to national economy, welfare, and prestige.

What Executive Branch Leaders Should Do

The President and top Executive Branch leaders should vigorously endorse the development of U.S. space enterprise and space industrial competitiveness as national goals.

President Bush has endorsed space commerce in his congressional budget address and in the Executive Order reestablishing the National Space Council. Continued White House support and public endorsements from the NASA Administrator and the Secretaries of Defense, Commerce, and Transportation will convey the significance and priority of these goals to the Public-Sector Team — the relevant government departments and agencies working together as partners — and to the nation.

Centralize leadership for civil and commercial space in the Executive Branch under a single authority — the Director of Civil Space.

The President should appoint the NASA Administrator, a member of the National Space Council, as Director of Civil Space to coordinate the civil and commercial space activities of all departments and agencies involved in such activities. The Director would draw on NASA space expertise, facilities, and technology to advance U.S. space enterprise and industrial competitiveness.

Within the Space Policy Advisory Board, form a permanent industry advisory committee to advise the National Space Council — and, if appointed, the Director of Civil Space — on U.S. space enterprise and space industrial competitiveness.

As a subcommittee of the recently established Vice President's Space Policy Advisory Board, the industry advisory committee would evaluate, monitor, and offer counsel on national strategies, plans, and actions on space enterprise and space industrial competitiveness. Members would be drawn from the top ranks of U.S. industry, and the financial and academic communities.

Establish a national plan to improve U.S. space industrial competitiveness

The Director of Civil Space, assisted by the industry advisory committee, should establish specific goals for each sector of U.S. space enterprise and develop a plan for ensuring U.S. leadership and competitiveness in commercial space. A well-conceived plan would assist in unifying actions and stabilizing national policy.

What Government Agencies Should Do

Provide vigorous support to U.S. space enterprise

For U.S. space companies to compete successfully, vigorous government support is urgently needed. Space enterprise in the United States will expand with the civil and defense sectors of the Government acting as sponsors and customers. Broader support from NASA is especially needed in new market sectors. NASA funds for commercial space development should be substantially increased to —

- Ensure routine space transportation, at modest or no cost.
- Augment and focus the Centers for the Commercial Development of Space.
- Provide facilities, infrastructure, equipment, and expertise.
- Continue advanced research and technology supporting the commercial development of space.

The Departments of Defense, Commerce, and Transportation should expand programs to encourage space enterprise and competitiveness, and work with NASA as partners committed to developing a robust and competitive space industry.

Seek ways to assist new space enterprises in attracting capital

There are many ways that government agencies can share the risk or reduce the costs of space research, startup, and transportation for emerging space enterprises. Examples include providing free launches for certain R&D experiments, encouraging scientist exchanges with industry, and acting rapidly on private-sector requests. In addition, the Government could use such creative financing mechanisms as guaranteeing the principal on private-sector zero-coupon bonds. These measures will make space enterprise more attractive to capital markets.

Be prepared to serve as an anchor tenant or key customer of new private-sector space infrastructure, products, and services

Government needs should be met through the purchase or lease of commercially offered infrastructure, products, and services. The Government should not influence the design of infrastructure in a way that would prevent later use by the private sector.

What Congress Should Do

Congressional committees have played an important role in promoting the development of space enterprise. In addition to supporting and encouraging the initiatives taken by industry, the Executive Branch, and governmental agencies, Congress alone can act on the following two recommendations.

Authorize multiyear commitments to purchase or lease space goods and services

Long-term customer commitments are essential to persuading private-sector investment in space enterprise capital formation and technology development. As a customer, the Government should be able to commit to lease or purchase over a 5- to 10-year period.

Pass legislation to provide substantial incentives to industry for investing in space technology

Space technology is a strategic tool for the United States. Establishing and holding a competitive position will require years of private-sector investment, despite considerable risk and market uncertainty. Recognizing the strategic and economic benefits of past efforts to develop shipping, railroads, and airlines, the United States should offer R&D, capital gains, and other investment incentives to develop a commercial space sector that is a strong competitive force in the world market.

Other Recommendations

In addition to these key recommendations, the Commercial Programs Advisory Committee's full report offers a number of recommendations in four functional areas:

- **Policy Stability and Consistency** — measures dealing with policy formulation, implementation, and follow-up.
- **International Competition and Cooperation** — measures addressing space competitiveness commitment, protection of intellectual property, and rational unified approaches to administering technology transfer policy, equal market access, and strategic goal setting.
- **Finance and Private Industry Incentives** — measures the Government can take to ease startup burdens and foster the assembling of needed capital for new space ventures, including expanding the NASA Centers for the Commercial Development of Space and enhancing their industry focus, and broadening government procurement guidelines to support use of commercial products and services.
- **Political and Public Opinion Process** — measures to expand knowledge of the potential of space enterprise throughout the Government, industry, finance, science, and academic communities.

Conclusion

The nature of the space race has changed. In the past, America's leadership was built on excellence in space exploration and technological advances. In the future, success in space will be determined by an expanded set of measurements.

In the 1960s, the key question was which nation would be the first to land on the moon. America won that race.

In the 1990s and beyond, an increasingly important question will be which nation will make the best use of space to gain an advantage in the global market. America cannot afford to lose this new space race.

About the Committee

In July 1988, the Commercial Programs Advisory Committee (CPAC) was formally created to provide NASA with a diverse, high-level industry perspective on commercial space business. As a subcommittee of the NASA Advisory Council, the group was chartered to assist NASA by reviewing policies and programs and by recommending strategies to implement national space policy goals. The mission is to promote greater investment and participation by the U.S. private sector in America's civil space program.

Edward Donley, Chairman of the Executive Committee of Air Products and Chemicals, Inc., was named to serve as CPAC chairman. Committee members were drawn from the ranks of U.S. corporate chief executive officers and their university counterparts.

Chairman

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Chairman, Executive Committee
Air Products and Chemicals, Inc.

Robert Anderson
Chairman of the Executive Committee
Rockwell International Corporation

Rand V. Araskog
Chairman and Chief Executive Officer
ITT Corporation

James K. Baker
Chairman and Chief Executive Officer
Arvin Industries, Inc.

Paul Bancroft, III
Retired President and Chief Executive Officer
Bessemer Securities Corporation

Dr. Thomas A. Bartlett
Chancellor
The Oregon State System of Higher Education

Robert E. Campbell
Chairman, President and Chief Executive Officer
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Joe B. Wyatt
Chancellor
Vanderbilt University

Introduction

Commercial development in space poses one of the most difficult challenges U.S. industry has faced. The inherent technical and market risks, the magnitude of investments required and the longer payback periods characteristic of space ventures are daunting enough. In space business, however, these risk factors combine with an unparalleled level of government involvement here and abroad. The U.S. government--in contrast to foreign governments--has yet to develop a stable and reliable approach to supporting industrial space applications. Thus, it is understandable that few U.S. companies have been able or willing to pursue potential space-related commercial opportunities.

Yet a perception of the great economic potential of space remains. Space offers both direct and indirect economic returns: new industries creating new jobs and growth opportunities in the next century; and the potential for revitalizing existing industries with space-related technologies. The possible economic returns have motivated other countries to make substantial long-term commitments to develop commercial space capabilities.

This country has made an enormous investment in its space capabilities--at first for political and prestige reasons, and increasingly for critical national security applications. At the end of the Apollo program, the U.S. could take justifiable pride in its clear pre-eminence in space achievement.

Now, at the very point that the U.S. should be getting a return on its national investment in space technology, it appears to be faltering. Other nations have made significant strides in developing their own capabilities, in many areas developing near parity. They have directed much of their efforts at--and the erosion of U.S. position has been most apparent in--commercial applications. Given the considerably higher level of U.S. space expenditures, the rate of increase in foreign capabilities is cause for national concern.

Secretary of Commerce C. William Verity, concerned about these developments, convened a Commercial Space Advisory Committee to make recommendations on how to enhance U.S. competitiveness in this vital new area. I was privileged to chair this Committee, which included outstanding individuals with a wide range of interests and experiences. I am grateful to the members of this Committee for giving generously of their time to address this important national issue.

This report presents the views of the Committee concerning both problems and potential solutions. The three primary issues which must be addressed by the new Administration and Congress are: 1) providing a stable government space policy, 2) expanding the government's commitment to basic research and development funding, and 3) developing low-cost, assured access to space.

Reproduced from Report of the Commercial Space Advisory Committee to the Secretary of Commerce. Washington, U.S. Dept. of Commerce, 1989. 38 p.

The recommendations of this Committee focus primarily on the first two of these issues, namely: the instability of government policy and R&D programs affecting commercial space ventures. The Committee identified major sources of instability and basic issues which must be resolved by government and industry leaders. Until these fundamental issues are addressed and reasonable consensus developed, the policy disarray concerning civil and commercial space activies is likely to continue.

The Committee reviewed a wide range of potential recommendations intended to facilitate expanded private sector involvement in space. These deliberations led to a strong consensus that a new relationship between government and industry in space was both possible and highly desirable. The Committee believes the new relationship recommended draws effectively on the respective strengths of government and industry. Specific recommendations are enumerated here to implement this new relationship.

Commercial development in space can make a significant contribution to the nation's overall space posture by stimulating innovation, expanding the range of space activities and capabilities, lowering costs and reducing risks for government space programs. It can contribute substantially to maintaining U.S. space leadership in an era of severe budget constraints.

To the extent that the recommendations of this report are implemented, the Committee believes that industry can and will expand the scope of private initiative and investment in space related activities. Conversely, if implementation actions are not taken quickly and in a manner which promotes confidence in long-term policy stability, the Committee is seriously concerned about the ability of the U.S. to be competitive in this promising new frontier for economic growth.

Edward E. Hood, Jr.
Chairman

COMMERCIAL SPACE ADVISORY COMMITTEE MEMBERS

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I. Industry View of Commercial Space Opportunities

Events of the last few years have forced a more realistic appraisal of the near-term prospects for commercial space development. Space commerce is still very young, including one mature sector and others ranging from newborn to embryonic. But both the U.S. and its economic competitors have recognized the *long-term potential* and *formidable near-term challenges.* This section presents a summary of industry's perspective on the opportunities, the current state of development and the problems which must be solved.

A. Economic Importance of Commercial Space Development

A wide range of economic activities have been projected for space. Thus far, the only proven commercial application is communications satellite service. Near-term industries, such as launch services and remote sensing information services, are being established; however, the timing of self-sustaining markets for either is difficult to predict. Future activities, such as industrial research and materials processing, have shown promise based on the limited research activities that have been conducted to date. The value, timing and potential magnitude of such activities cannot be reliably estimated. Further potential activities, such as manufacturing or large-scale energy generation, await a significant reduction in space transportation and operations costs.

Although the long-heralded economic potential of space is being realized only slowly, the conviction remains that the potential impact of commercial space development could be very large. There are a variety of factors that support this conviction.

Radically Different Environment & Vantage Point

Space offers the first opportunity for humankind to operate in a radically different physical environment. Many of the fundamental processes on which our current industrial base is built are dependent in some way on the force of gravity. Little basic science has been done to date on fundamental physical processes in the very low gravity ("microgravity") environment of space. Therefore, there exists at least *a potential for breakthroughs and unforeseen applications.* In addition to low gravity (effectively, one ten-thousandth to one-millionth that experienced on earth), space makes readily available a hard vacuum and very low temperatures, which may prove useful for particular processes.

Even if major breakthroughs do not occur, the ability to vary such fundamental physical parameters in experiments should provide new insights with which to refine existing industrial processes. Technology competition is putting increasing emphasis on advanced material properties. Space-based research can speed up the research cycle on new materials. For example, solid crystals of large proteins which cannot be made on the ground, can be made in space. These crystals accelerate the process of analyzing the structure of the proteins and formulating new pharmaceutical products. Similarly, the space environment should accelerate the growth or increase the size of new electronic materials. *The economic impact of this acceleration can be very large, if it translates into earlier patents.*

Another unique attribute that space offers is vantage point, which has already been exploited for communications, weather and remote sensing satellites. It would be prohibitively expensive to try to duplicate, using other means like aerial photography, the monitoring that is possible from orbital position.

Wide Range of Possible Applications

Space is a new place in which to pursue a wide range of traditional economic activities: communications, transportation, resource management information, navigation, meteorology, materials (raw and processed), and energy generation. *In fact, it is difficult to identify a single economic activity which is not a candidate to benefit at some point from space development.* Some may benefit as a direct producer of new or improved products and services; others as customers for space-related services, or as beneficiaries of space-based research with which to develop new products or improve existing ones.

All industries benefit from improved communications. Remote sensing offers information for the management of renewable resources (forecasting, pest control for crops, timber, rangeland, watershed management), environmental monitoring (land and ocean pollution, acid rain, climatic change), and prospecting for nonrenewable energy and mineral resources. The transportation industry and all of its customers stand to benefit from more accurate and timely navigation and position reporting. Position reporting combined with messaging capability could even be a boon for individuals. Technology development and materials research could potentially benefit such manufacturing and process-based industries as metals & alloys, polymers & chemicals, electronics, pharmaceuticals & biological materials, glass & ceramics, fluids handling & transport, and combustion.

Strategic Positioning

The present limited number of space-capable countries automatically limits the potential competition in space. Economies of scale could introduce further barriers to entry in space businesses, such that the first company/country to develop a new service or product could develop a preemptive lead. This may occur because of patents or limited market size precluding competitive offerings, such that the "first to market" wins. Economic competition in space is technology dependent, so there are continuing opportunities for strong innovators like the U.S. and limited likelihood of labor cost being a key factor of competition.

Additional Returns from Secondary Applications

Secondary economic benefits from space may always outpace direct economic gains, although secondary benefits are very difficult to measure. Attempts to measure the economic impact of the U.S. space program over time have cited economic returns as large as fourteen to one for every dollar spent on space development. Such analyses can never be done in a completely satisfactory manner. It is useful to note, however, the kind of technologies that are pushed by space operations: light-weight, high-strength and high-temperature materials; cryogenics; high-speed computing; fault tolerant computing; high-speed communications, including electroptics; artificial intelligence, robotics, expert systems, teleoperators; and possibly biotechnology through biological research to support man in space. *These technologies include many that have been projected as contributing to new waves of economic growth in the next century.*

The net effect of the factors described above is that space development could have tremendous "economic leverage" for the dollars spent.

B. Differing Maturity of Space Industry Sectors

Space business is not a single monolithic industry. Different sectors of commercial space activity are in varying states of maturity. It is useful to think of six sectors:

- communications (point-to-point relay, point-to-multipoint relay, direct broadcasting)
- transportation (suborbital or low-earth-orbit launch, transfer to other orbital positions including geosynchronous; wide range of payload sizes)
- remote sensing (satellites returning digital imagery of the earth's surface and atmosphere from low-earth or geosynchronous orbit for purposes of environmental monitoring, resource management and meteorology)
- navigation/position reporting (position reporting for maritime aeronautical and land vehicles)
- facilities/support services (support services on the ground or prospectively on orbit, including communications, operations & maintenance, propellants, energy, or facilities which can be used for same)
- research & process development (utilizing suborbital or orbital facilities to conduct experiments relating to properties and processing of all types of materials).

The current degree of maturity and the rate of maturation of each of the above sectors is affected by:

- whether or not the space-based product or service addresses an existing market (also, the size/dynamism of the affected market);
- whether the new product or service provides sufficient economic advantage to merit rapid acceptance;
- how sound the base of knowledge is that is being exploited;
- whether the demand is primarily private or government; and,
- the degree/nature of competition.

Thus far, among space businesses in the U.S. there has been: one example of a successful commercial application (comsats); recent transition to commercial operation of a previously government-dominated activity (launch services); early market development and continuing transition from government operation for a relatively new service (remote sensing); and other speculative applications (materials processing) awaiting the development of reliable, lower cost access to space. Commercial facilities and support services will grow as the other sectors grow.

Early applications offered an enhancement of capability for a rapidly growing, existing market (communications). The fact that the application matched well into the existing market is part of the reason why communications satellites established themselves so quickly. Other space applications offer such radical advancements in capability or entirely new capabilities that the market is hard to define; for example, remote sensing and position reporting. For the former, extensive market development has proven necessary. The latter may address a large existing need, and hence may grow more rapidly. When and how quickly materials processing takes off will be determined by the availability of facilities and whether early, profitable activities are found.

Each sector will transition through similar growth stages. With the exception of comsats (which are now fairly mature), the government will be a dominant or substantial early customer and catalyst, with the eventual growth of increasing or dominant private interest. All sectors are facing increasing foreign competition.

The timing of growth will vary for each sector; for most, the government may remain the dominant customer for a significant period. Therefore, the process of commercial development is very dependent on government practices.

C. Intense International Competition

The U.S. is the only country interested in space which is attempting to develop a separation between government space activities and private, commercial enterprises in space. Other space-faring nations conduct virtually all space-related activities as government-managed programs. The motivations for the degree of government management, direction and funding include:

- prestige (space activities place country among the first rank of nations);
- national security (unique capabilities for surveillance, communications and strategic weapons delivery);
- positioning for future economic growth opportunities (subsidization to assure competitive position because of projected returns; newly developed countries view it as vital not to let a "space gap" develop, as it is seen as the key to the future).

Much of the early demand in new space sectors is government generated or controlled. This is more true abroad than in the in U.S. because of government-controlled communications sectors. All national security, and virtually all scientific research are, by nature, government controlled. So protectionism is the norm rather than the exception in space trade.

The current markets for space-related goods and services are small for the number of interested and potential players. Launch services and remote sensing are both very competitive and likely to become more so in the next decade. Foreign satellite manufacturers will start to challenge U.S. preeminence soon. Thereafter, competition will heat up in facilities and supporting services, both on the ground and in orbit.

Investments to enter the space game have historically been relatively large and long-term, particularly the costs of developing initial infrastructure and capabilities. Even after the initial investments are made, space investments tend to be longer term than most commercial investments.

Factors such as the term and magnitude of investment and the uncertain markets for new space goods and services will tend to keep foreign governments involved in space development. *The degree of foreign government involvement makes it difficult for U.S. private, commercial concerns to compete.* If foreign subsidization continues in developing commercial space activities, U.S. companies will be constrained to the U.S. domestic market in making investment decisions. Given the diffuse early demand for space goods and services, U.S. operators need to have access to the global market to remain competitive. If subsidized, foreign competitors are allowed free access to the U.S. domestic market, private commercial concerns in the U.S. may very well be unable to compete.

D. Unstable Government Policy & Programs

The degree of intrusiveness of the U.S. government in space is unique among established or projected areas of industrial activity. There are a number of reasons for the extent of government involvement in space:

- space is by definition an international environment; the U.S. government is party to treaties which impose on it responsibilities (such as, preventing orbital placement of weapons of mass destruction and accepting liability for damage from space objects) in addition to the domestic concerns it has (e.g., ensuring public safety);
- all space capabilities or technologies at this point are sensitive from a national security standpoint;
- space development began as an international prestige competition; a culture of government management/control developed to assure fulfillment of these government objectives;
- the government is the dominant customer for space goods and services (to fulfill a wide range of civil and national security missions) for the foreseeable future in most areas of potential commercial space operation.

The extensive government activities support a presumption, left over from the early days of space development, that space is naturally and unavoidably a government function. This view holds that private, commercial space activity may not be possible, or certainly not possible for a long time.

In the last decade or so, there have been repeated major swings in government policy, as it affects actual or potential commercial space activity. By some counts, there have been eight major shifts in Federal policy toward aeronautical communications. There have been five major shifts in Federal policy toward satellite communications and mobile ground stations. In remote sensing from space, there have been at least 11 major policy shifts. Over the past 30 years, there have been seven major policy shifts in the role of NASA with respect to research and development. *These swings have resulted, among other things, from differing perspectives on what the proper government role is in relation to commercial operations in space.*

Furthermore, funding for, and successful completion of, government space programs intended to support commercial space activities is increasingly uncertain. Prominent examples include the shuttle and space station--facilities designed in part to support commercially oriented research. Space shuttle availability has been drastically reduced from what had been promised and, given current circumstances, will never approach the levels projected to support commercially oriented research. The space station operational date has already slid five years, its cost has doubled, its projected performance has been reduced, and the prospects are highly uncertain for the level of funding needed to achieve the current plan, given the severe budget constraints.

Neither government commitments explicitly to "commercialize" a government developed space technology (LANDSAT), nor programs to push technology intended for commercial application (ACTS) have been reliable.

At the release of this report, there is no evidence that the continuing public discord between branches and among agencies of the government concerning how best to support commercial space development has in any way diminished. Government unreliability/instability constitutes an uncontrollable risk for industry. Some of the risk factors encountered by commercial space ventures can be managed (costs, technology development, market development). Other risks can be insured (accidents, random failures), although some types of space insurance have been difficult to secure at times.

Unfortunately, government stability and reliability are particularly important for commercial space development. Relative to other potential investments, space activities are viewed as higher risk. Government dominance combined with government instability and unreliability compounds this problem.

The instability/unreliability of US government commitments contrasts rather sharply with the stability of government commitments made by our competitors in space: for example, five-year funding commitments by European Space Agency (ESA) member countries; Japan's long-term space development plan in concert with its industry; and the inexorable expansion of Soviet space activities.

E. Eroding U.S. Competitive Position

At the end of the Apollo program, the U.S. was clearly pre-eminent in the world in space technology and achievement. With the massive commitment of fiscal and human resources made to that program the U.S. developed a 10-15 year technology lead. *Unfortunately the U.S. failed to capitalize in economic terms on this technology lead.*

Some catching up by U.S. trading partners was inevitable, but at this point European industry has established near-parity in many areas of launch and satellite technology. Japan and China are closing behind them. Recent estimates of Soviet space capability suggest that Soviet Union could achieve overall dominance with the next generation of more sophisticated satellites, combined with its much more robust launch capability.

To achieve closure, the Europeans in recent years have been ramping up space expenditures significantly. The Japanese are beginning to do so. The Soviets have always maintained a steady, relatively high level of funding to support their space activities.

However, given the dominant position of twenty years ago and relative level of U.S. space expenditures since, one must view the U.S. competitive position as having eroded considerably.

Much of damage has been self-inflicted:

- **Drastic Budget Cuts After Apollo**

  Between peak Apollo program funding in 1967 and the end of the program in 1972, civilian space funding was cut in half (in constant dollars). This drastic contraction forced many trained and talented people out of the program. It further confronted an agency accustomed to "blank check" funding and unquestioned public support with austerity. The drastic funding cutback dealt a devastating blow to the momentum built up in the first ten years of NASA's life.

- **Budget Uncertainties**

  A compounding aspect of the budget problems of the 1970's and early 1980's was that, not only were budget levels low relative to the program objectives, but they were highly uncertain. It is very difficult to run long-term programs efficiently with continuing uncertainty about what resources will be available at any point in time. To survive, program managers and agencies concentrate on clearing budget hurdles, rather than technical ones.

- **Program Decisions**

  After Apollo, the civilian space program was conceived as a series of "giant steps," focused primarily on manned space operations. This approach, combined with the aforementioned budget constraints, forced program decisions which, in retrospect, were misguided. The decision to eliminate the "mixed-fleet" concept and rely exclusively on the shuttle has proven to be a costly error. The shuttle itself, while a remarkable engineering achievement, will never achieve the performance it was supposed to--in terms of cost, reliability and flight rate.

- **Policy Vacillations**

  Repeated changes in policy and program orientation have occurred. Every change of direction costs time and money. Experience with policy and funding variability gives industry little confidence that it should invest its own money, based on or in concert with government programs. This has thwarted the process that occurs elsewhere where industry builds on the technology base developed through government-sponsored R&D to exploit commercial opportunities in new technology areas.

- **Lack of Continuing Technology Advancement**

  Cost growth in the operational, manned space programs combined with budget constraints diverted resources that would otherwise have supported research and advanced technology programs. NASA's own advisory committees have criticized the lack of substantial technology advancement in many critical areas for 10-15 years. Some effort is now being made to address this situation with specific "technology push" programs (Pathfinder and CSTI), although near-term funding for these programs is very limited. There is no "quick fix" for the consequences of the long-term erosion.

It should be noted that U.S. military space operations have not been subjected to the same policy and funding vacillations that the civil space program has. U.S. military space technology is still pre-eminent in the world, particularly in the areas of surveillance and communications; although the launch capability to support national security space operations will take some time to re-build. Because of the sensitivity of military space technology, this technology has been less available for commercial applications.

Where the U.S. has lost the most ground is in the area of prospective commercial applications. What shuttle capacity has been available was used primarily to launch government and commercial satellites. Little room has been made available for space-based research with commercial potential. Ironically, limited shuttle availability combined with the agreements reached with the European Space Agency concerning use of Spacelab has resulted in considerably more access to space aboard the shuttle for commercially oriented research by foreign companies than by U.S. companies. Much greater programmatic emphasis is evidenced in Europe and Japan on coordinated strategies directed at developing commercial opportunities.

F. Challenge Of Private Investment In Space

Independent of the degree of government involvement in space, would-be commercial space ventures face a daunting set of business problems:

- subsidized foreign competition
- technical uncertainty
- market uncertainty
- export control sensitivity
- regulation/licensing
- international environment (legal recourse & proprietary rights problems)
- extreme liability exposure (launch failure)
- long lead-times
- large up-front costs
- access to government facilities required

For each of the business challenges listed above one can identify companies and industries which have successfully dealt with the problem. In fact, international economic competition usually requires companies to deal with many of these problems. The development of new space businesses is problematic because it combines all or most of the above factors with the government acting as a dominant and unreliable player.

In spite of these problems, the potential of space commerce remains. If only because of the steadily developing pursuit of commercial opportunities in space by our economic competitors, we cannot afford not to compete as aggressively as possible.

II. National Objectives and Priorities in Space

The U.S. pursues a range of objectives in three different areas of space endeavor: national security, civil and commercial. The "national security space sector" includes both military and intelligence space activities. The "civil space sector" includes all civilian government agencies which conduct space activities, such as NASA and NOAA, or which have space-related responsibilities, such as the Departments of Commerce and Transportation. A "non-governmental, market-driven commercial space sector" was recognized in national space policy for the first time in January 1988.

The most recent statement of national space policy (National Security Decision Directive signed by President Reagan on January 5, 1988) set six overall goals for the United States in space:

1. to strengthen the security of the United States;

2. to obtain scientific, technological, and economic benefits for the general population and to improve the quality of life on Earth through space-related activities;

3. to encourage continuing United States private-sector investment in space and related activities;

4. to promote international cooperative activities taking into account United States national security, foreign policy, scientific and economic interests;

5. to cooperate with other nations in maintaining the freedom of space for all activities that enhance the security and welfare of mankind; and,

6. as a long-range goal, to expand human presence and activity beyond Earth orbit into the solar system.

The President's policy established policy, objectives and guidelines for each of the two government space sectors. With respect to commercial space activities, the President's policy directed that: 1) "the United States government shall not preclude or deter the continuing development of a separate, non-governmental Commercial Space Sector," and 2) "Governmental Space Sectors shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with potential commercial applications that preclude or deter Commercial Sector space activities except for national security of public safety reasons." The policy guidelines define "commercially available" to mean that the good or service is currently offered commercially, or if it could be supplied commercially in response to a government service procurement request.

The policy directive takes several very positive steps in defining a constructive relationship between industry and government in space that supports commercial development. It defines fairly clearly the circumstances under which governmental space agencies must buy commercial space goods and services. It overcomes the problem of government space activities overhanging the development of a commercial market by stipulating that if space goods and services could be supplied commercially, then government agencies must use them. The policy uses a negative standard ("shall not preclude or deter...") for government behavior rather than a positive one ("shall foster, encourage, promote..."), because it is easier to interpret.

The policy also contained stipulations addressing other commercial concerns, such as encouragement of a free and fair trade environment in commercial space goods and services, and encouragement of technology transfer from U.S. government agencies to the private sector.

While the strongly pro-commercial tenor of the policy was welcomed by industry, the policy directive failed to create the stability that industry needs, for several reasons. *First, little effort was made to effectively implement the policy.* While the policy directs government agencies to buy commercial space services, current procurement regulations (and possibly procurement statutes) would have to be modified to accomplish this. No noticeable effort was made to accomplish this. Congressional support would be very desirable, if not mandatory, to effect the reforms to the procurement process necessary for the policy to be successfully implemented. No apparent effort was made to seek Congressional endorsement or support for such reforms.

A Commercial Space Initiative that offered 15 "implementation initiatives" was released by the White House concurrent with the announcement of the new policy. While these initiatives were generally well received by industry, only one initiative (for the government to lease space on a Commercially Developed Space Facility) received serious agency support. When that initiative encountered resistance on Capitol Hill, the White House failed to provide visible support. None of the other elements of the President's Commercial Space Initiative have been pursued with noticeable vigor. The Congressional resistance to both the national space policy and the one visible attempt to implement it, combined with failure of the White House to provide support, gave industry little confidence that a stable new policy environment had been developed.

A second cause for industry concern was that *no permanent, accessible policy process was established for the resolution of potential issues or conflicts in the commercial space arena.* The Economic Policy Council (EPC) of the Cabinet was identified as the forum for commercial space issues; however, the EPC is not permanently chartered, as the National Security Council (NSC) is. The EPC was created with the Cabinet reorganization in President Reagan's second term and may very well be eliminated in the new Administration. The NSC was identified as the forum for review of national space policy. Therefore, by default, commercial space policy issues could end up back in the NSC, where industry has little access and considerable cause for concern about how its interests will be weighed against other national interests in space.

A final industry concern about whether the current national space policy can bring about greater stability in the environment for space commerce is that *it failed to establish any priorities for the civil space program.* The stated objectives for the civil sector (primarily NASA) are very general space science and technology goals, with no insight into prioritization of the goals. The accompanying guidelines provide nothing more than general ratification of NASA's current program activities. The lack of priorities leaves industry with little insight into how its interests may fit into NASA program plan, nor any basis for raising questions about how its interests are being supported in light of established priorities.

The need for stability--in policy, programs, and process--and the effect of instability on commercial space development are examined in the following section.

III. Need For Government Stability

The primary problem facing U.S. commercial space ventures is the instability of U.S. government policies and programs. There are three types of instability which must be corrected, if U.S. industry is to be able to operate efficiently and compete effectively in international space markets: instability in national space priorities, program funding, and governmental process.

A. Priorities

From industry's perspective, the government's priority on commercial space development is unstable, as evidenced by erratic program commitments and funding. One of the shortcomings of U.S. space policy highlighted above is that it has failed to establish priorities among the many activities identified for the civil space program. The general direction given the civil sector is that its "activities shall contribute significantly to enhancing the Nation's science, technology, economy, pride, sense of well-being and direction, as well as United States world prestige and leadership." A broader mandate is difficult to imagine.

The civil sector is further directed to conduct activities that comprise "a balanced strategy of research, development, operations, and technology for science, explorations, and appropriate applications." Without priorities, on what basis is "balance" established and maintained?

The following six specific objectives are defined for civil space sector activities and do little to clarify their scope or priority:

1. to expand knowledge of the Earth, its environment, the solar system, and the universe;
2. to create new opportunities for use of the space environment through the conduct of appropriate research and experimentation in advanced technology and systems;
3. to develop space technology for civil applications and, where appropriate, make such technology available to the commercial sector;
4. to preserve the United States preeminence in critical aspects of space science, applications, technology and manned space flight;
5. to establish a permanently manned presence in space; and
6. to engage in international cooperative efforts that further United States space goals.

The fundamental issue of priorities which was not addressed was whether the primary purpose of the civil space program (in particular NASA) is to advance manned space activities, per se, or to pursue science and technology advancement, with manned activities representing a subset of the total. The issue of priorities for NASA's activities is important for two reasons. *The primary purpose of the agency defines its orientation and culture. A definition of priorities also provides greater stability or predictability in the face of severe budget constraints.*

Since its inception (and particularly since President Kennedy's challenge that created the Apollo program), *NASA has pursued manned space activities as its de facto first priority*. This is evident, though not stated explicitly, in current national space policy. Manned space activities do contribute dramatically to fulfillment of certain national objectives in space: in particular, the directives relating to national pride, sense of well-being and direction, as well as United States world prestige and leadership. The effect of manned space programs in demonstrating technological preeminence is not to be underestimated. For example, the space shuttle has demonstrated itself to be a potent political symbol.

NASA and its Congressional supporters have always felt that only the presence of man in space would maintain the political support for the program. Manned space activities have been sold as being necessary to support scientific and commercial objectives, in spite of the fact that *many in the scientific and commercial communities have indicated for years that their objectives could less expensively and more reliably be supported with unmanned programs*. Further, these communities have maintained that the emphasis on manned space activities has redirected resources away from their pursuits and left them with low priority and unreliable access to space.

A continuous tension has existed because of the extent to which the organizational orientation of the civil space program toward manned space activity has shaped the culture and decision making of the civilian space effort. Decisions on how to pursue scientific and commercial interests are made after a commitment has been made to develop operational manned systems. Hence, the other objectives are not being pursued as efficiently as they might be.

The Committee does not wish to state a position on the degree to which manned space activities should constitute the primary priority of the civilian space program. *That is appropriately a political decision.* **However, the Committee does wish to highlight the fact that such a commitment does have significant implications for how our other national objectives in space can best be pursued.**

B. Program Funding

In contrast to its economic competitors, the United States pursues long-range technology development programs with year-to-year funding commitments. Seldom does the United States government make a firm, multi-year procurement commitment. In fact, the process of continuing resolutions to which the Congress has resorted leaves the level of near-term resources that will be available to government program managers uncertain for a substantial period of every year.

The instability of the annual appropriation process in the U.S. and the various costs and inefficiencies it introduces have been frequently cited by groups making recommendations on how to improve the effectiveness and economy of government operation. However, such recommendations have not been implemented because of resistance by Congress and the Office of Management and Budget to long-term commitments which they perceive as limiting their future options to control funding.

The contrast between the U.S. and foreign patterns of government funding is most apparent in space, where there has been a clear recognition by our economic competitors that it is most efficient to fund long-term development efforts like space in a long-term stable manner. The European Space Agency (ESA) requires five-year commitments by its members for 120% of the projected funding level required to support approved ESA programs. The Japanese have also developed a pattern of long-term funding by both government and industry to support space technology development.

Annual appropriations of R&D projects is particularly inefficient, because project managers must engage in constant-re-budgeting and re-programming exercises, as projected funding levels vary. Furthermore, project managers are motivated to produce near-term results to try to minimize funding cuts, whether or not near-term demonstrations represent the most efficient development path. Efficient funding of facilities and equipment upgrades to maintain state-of-the-art facilities is also difficult in this environment.

In the face of intense technology-based competition from abroad, the Administration and Congress must seriously consider whether the benefits to the government of multi-year funding commitments do not outweigh whatever benefits accrue from making annual changes in long-term programs.

The ability of the federal government to make a reliable (i.e., "bankable") commitment to purchase future services is critical to the development of a "commercial" relationship between industry and government, that is, private design, funding, construction and operation of space systems to support government (and other) requirements. *Without firm commitments for future services, the private sector will not be able to bear the risk of capitalizing commercial space systems.*

C. Process

Substantial friction has been observed between branches of government, among agencies, and between the government and commercial space ventures over the last five years. Industry response to potential commercial development opportunities will depend upon what mechanism is set up for resolving such disputes. The level of industry confidence will be based upon whether fundamental governmental stability is likely and how well industry's interests are represented. *This confidence (or lack of it) will determine what kind of role the private sector is likely to play in space.*

National space policy involves the balancing of different national objectives: national security, scientific advancement, foreign affairs, economic development. Each of these areas affects the others in some way. It is natural that conflicts arise. *What is important for all parties involved is that such conflicts be resolved in a timely fashion, with each interest fairly represented in the process.* Conflicts will be minimized to the extent that national space policy goals are clearly stated, the priorities among national space objectives are defined, and the responsibilities and relationships among different government agencies are specified.

Unlike the other national space objectives (which are, by nature, government functions), economic development is effected by private companies. Commercial space development has clearly had lowest priority among government space agencies. *Commercial space interests must be appropriately represented in* *this process, by an agency which can balance potentially conflicting program interests.*

For commercial space operators to have confidence concerning the government's role, they must believe:

1. **that their interests will be fairly represented**
2. **that they understand how their interests are perceived in relation to other national interests, and**
3. **that the process to resolve conflicts is stable, predictable and reliably quick.**

IV. Government/Industry Relationship

Despite the commanding space technology lead the U.S. held 20 years ago, and despite the U.S. having outspent its economic competitors by a considerable margin in the interim, this country has suffered a dramatic erosion in its competitive position in space applications. *The respective roles of the government and industry in space development must be re-evaluated to define a more productive relationship to assure future U.S. competitive strength.*

Because of the range of government concerns in space, there is a complex pattern of interaction between government and industry. The roles which the government plays affect most of the perceived risks industry faces in developing commercial space ventures. For example, the government, as the dominant near-term customer in many sectors, can significantly reduce "market risk" by clarifying its requirements, stabilizing its funding and making its procurement procedures more commercial in style. The government can also significantly reduce market risk by ensuring the development of fair international marketplaces for space goods and services. The government can help reduce technical risk by conducting R&D activities and promoting access to its research facilities. As the prime regulating authority (safety, export control, adherence to international treaties, proprietary rights), government also has an opportunity to minimize regulatory risk with carefully constructed and minimally intrusive regulatory regimes.

Other government actions have been proposed which would reduce risk for prospective commercial space operators, but distort efficient market development and are therefore not long-term efficient or desirable. For example, market guarantees have been proposed for several sectors.

Risk reduction need not constitute direct subsidy. Government can be most beneficial by exploiting its various roles to efficiently reduce risk, that is, reduce risks in ways which do not distort the developing markets for space goods and services here and abroad. In addition, as directed by current national space policy, the government should conduct its space activities in a manner which does not preclude or interfere with commercial space activities (except for national security or public safety reasons). Detailed recommendations are provided in Section VIB.

Industry plays several roles in relation to government. It can be a contractor to the government on government-managed space projects, a commercial service provider, a user of government space-related research facilities, or a partner in cooperative R&D projects.

Where differences in outlook on the appropriate roles for government and industry have created the most controversy is in the area of government purchase of commercial space services. These differences derive from varying perspectives on:

- the meaning of "commercial" space operations;
- the prospects for commercial space activities (how real and when);

- the extent to which the government must manage space development and operations;
- the extent to which industry can be relied on to fulfill critical space objectives.

There is little hope for the government policy stability which is vital for commercial space activities, until a consensus can be forged among government and industry leaders on these basic issues and the policies which derive from them. These issues are examined in detail below.

A. Concept of "Commercial" Space Operations

It will be some time before commercial space operations develop, in the strictest sense of the word "commercial." That is, where "commercial" means private-to-private, for-profit transactions, largely independent of the government. This is the concept of commercial space activities often held by individuals who express the view that the discussion of commercial space operations is premature.

A more useful concept of "commercial," as it relates to space activities, is based on the nature of the transaction (terms and conditions) and the allocation of risk and responsibility, rather than who the customer is. The important characteristic is the extent to which private capital is at risk, in a competitive market environment, with transactions being conducted according to standard commercial practice.

The government demand for space-related services is large enough in some areas (launch and launch support services, communications, navigation and position reporting) to support competitive markets to supply the government's requirements. In other areas (remote sensing, space-based materials research, orbital services), if the government demand were properly aggregated, some in industry feel it might serve as the basis for competitive, commercial offerings.

The benefits to the government of structuring its demand for space services so that they can be commercially supplied are described in Section IV-E. The objective for the government is to define a relationship where private capital is at risk, based on the offeror's performance, but not at risk for things that are beyond the control of private companies--typically, government actions. Random events (such as launch failures) can be adequately managed through insurance. However, unpredictable government actions which significantly affect the profitability of a venture render commercial supply difficult or impossible.

Unfortunately, industry's experience to date with government attempts to "go commercial" is that industry ends up with the worst of both worlds: the expectation by the government that industry will bear increased risk without the authority or flexibility to properly manage such risks and without the profit potential to justify it. Three areas in which standard government and commercial practice diverge most dramatically are in the allocation of responsibility, determination of price and negotiation of terms and conditions.

For the government to realize the potential benefits of commercial supply, it must be willing to:

1. allow the commercial supplier full responsbility and authority to determine the best way to fulfill its contracted obligation;
2. accept market-determined prices, which allow commercial suppliers to account for increased risk, rather than regulating contract prices based on cost;
3. flexibly negotiate terms and conditions with potential suppliers.

B. Prospects for Commercial Space Activities

At issue here is whether self-sustaining commercial space activity is a near-term or long-term proposition, or whether true commercial activity is even possible in space. Specifically, is it premature to contemplate true commercial operation at this time, for sectors other than communications satellites? Do factors such as the degree of government dominance in space (here and abroad) effectively preclude true commercial development in space? If so, is it for the near term? Indefinitely? Do different sectors have different prospects for commercial operation? Depending on how one views the current prospects for commercial space activities, very different conclusions can be drawn about how best to proceed.

During the 1970's and early 1980's there was a prevalent view among supporters of commercial space development that space activity in general was so risky, or that it required such large, long-term investments that it was beyond the capability of the private sector to pursue on its own. Or, at a minimum, it was beyond the private sector until a more concrete demonstration of the economic returns had occurred. Consequently, this view held that the government should provide the necessary "infrastructure" common to all space activities, in order to reduce private sector exposure. This would allow private industry to make its investments directly in commercial applications.

It was also a common view of government space officials that private industry didn't really understand space operations, so it was something the government had to do. Presumably, once the government demonstrated the "commercial potential" of various technologies, then industry could exploit them. These views were a natural carry-over from the Apollo program approach to space. It's important to note that the generally accepted notion of "commercial" space activity was one in which the customer is a private commercial concern. Therefore, the shuttle was providing "commercial" launch services when launching communications satellites for private customers.

Foreign subsidization of "commercial" space ventures was used to support the view that commercial space activity was something that, for the near term at least, would be a government-managed and -directed activity. It was projected that private U.S. corporations would be unable to compete with subsidized competition from abroad. If other countries subsidized their commercial space concerns, the argument went, the U.S. had no choice but to follow suit, or it would lose out.

Those holding this view that true commercial space operation is not likely to occur for some time discount its importance and see the concept of commercial supply of space services to the government as artificial or pointless.

Several observations should be made:

1. *The view that commercial space development must be government-managed is self-fulfilling.* Private industry will not propose to do things in direct competition with government-funded programs. Hence, the "interest" or "ability" of industry to make investments in space will not be evidenced, if the government has "overhung" the potential areas of interest.

2. A growing body of contrary evidence has developed concerning the ability/willingness of private sector entities to take risks to get into space business. One of the best recent examples is the U.S. launch service industry which has invested hundreds of millions of dollars to enter a business with proven technology, but a poorly defined market and subsidized competition from abroad.

3. The ability of government to fulfill a self-prescribed role of all-purpose infrastructure provider is increasingly questionable, given past difficulties and the severe budget constraints under which it will have to operate for the foreseeable future.

4. As noted above, this concept of "commercial" space activity is unnecessarily restrictive. A more useful definition of "commercial" is based on the nature of the transaction, rather than who the customer is. Thus, if the government purchases space goods or services in a manner consistent with standard commercial practice, then it is a commercial purchase. This definition thus focuses attention on how risks and responsibilities are allocated between buyer and seller.

The conclusions of the Committee with respect to prospects for commercial space are as follows:

1. Clear differences exist in degree of maturity and the rate of maturation of different sectors (as described above in Section IB).

2. The timing/size of investment by the private sector is related to projected market size. There is no fundamental limit on the private sector's ability to make investments of the magnitude required for space, if market projections warrant it.

3. Most of the market for commercial space opportunities (other than comsats) for the foreseeable future is driven by government demand.

4. If the government were to present its operational space requirements as requests for commercially supplied services, it would vastly increase the near-term size of commercial space markets. The expanded market would create more competitive interest and justify larger scale private investment in space operations.

5. Government dominance will continue to be a fundamental concern of industry, but this in itself does not preclude commercial activity. Rather it should focus government and industry attention on how the government conducts its space activities. *There are different ways the government can satisfy its requirements in space, some of which interfere with commercial market operation and others of which do not.* Support of commercial market development should not interfere with the government's ability to satisfy its requirements (in fact

benefits are likely to accrue to the government, as described below.)

C. Government Management of Space Development & Operations

It is a fairly common attitude or expectation that the government must be in direct hands-on control of space development activities. This attitude has carried over from the Apollo program, where government effectively had to build an industry capability from scratch very quickly. The different pattern of government/industry interaction that developed has remained to this day. The continuing emphasis on manned space program has reinforced this style of management and operation. In fact, manned space operations are beyond the capability of the private sector to take on as a commercial venture for the foreseeable future, owing to their low commercial value, high risk, and high cost.

However, in virtually all areas of unmanned space activity, industry is fully capable of planning and executing operations on its own. Communications satellites have been privately designed, developed, financed and operated for decades. The manufacturers of expendable launch vehicles are transitioning fairly smoothly from government contractors to commercial operators. Because of industry's long-standing role as contractor on virtually all government space development and operations programs and the routine influx of NASA and DoD personnel to industry, there is no special expertise in government that is not available to industry.

The recommended relationship proceeds from the strong preference industry has for the government to specify what it wants done in space (requirements) rather than how it should be done (design specification). Industry is willing to bear risks that it can manage or control. One of the problems with traditional government procurement is that it introduces unmanageable risks: will the government still want the requested service (or be able to pay for it) when it is to be provided. Another negative aspect of traditional government procurement is the way it undermines or at least slows innovation. It further inhibits efficient long-term investments to increase productivity.

D. Industry Reliability

This issue deals with the extent to which industry can be relied on to fulfill national space objectives. To what extent does the government need to directly manage space operations and the development of space infrastructure? To what extent can/should the government rely on privately developed space systems? Is industry capable of making long-term, high-risk investments in space?

The issue of industry's reliability is key to resolving the fundamental relationship between government and industry in space. Depending on one's perception of industry's reliability to fulfill contracted commitments, one may choose to rely on industry or not to ensure the fulfillment of critical national space objectives.

A common feeling among government space officials is that direct management control and supervision is necessary to assure the achievement of national space objectives. Their concern is that companies may fail to perform, leaving a government space agency without a critical capability when it is needed. A view persists, as well, that the expertise resident in government space agencies is a necessary ingredient for successful space endeavors. A concern expressed by some government officials is that private industry will "cut corners," in ways that will affect the reliability or performance of the systems providing commercial services, unless there is direct governmental oversight.

The Committee's observation is that the issue of supplier reliability or contractor performance is one that industry deals with daily. Numerous techniques are available to ensure performance on a commercial contract, including large scale, complex and safety-sensitive projects such as refineries, power plants, and pipelines. Reliability and performance are very important in space, because, once deployed, most current space systems cannot be repaired. However, many commercial concerns deal successfully with very stringent reliability, performance and safety requirements. There are several aspects of the reliability issue:

Technical Expertise - There shouldn't be any doubt about industry's space technology capability. Over 80% of the nation's space scientists and engineers are employed in industry. It is in fact industry's expertise that government space agencies call on to pursue all major government space projects. The communications satellite industry develops (without government oversight) very advanced satellites which it sells commercially. Where government technical expertise can be usefully drawn on by industry is in the area of advanced R&D, where the government can, and should, develop advanced technology beyond the state of commercial application.

Management - Industry is fully capable (after 30 years) of successfully managing space projects. The project management techniques developed for space are fully imbedded in industry, including techniques for utilizing existing space technology or developing and qualifying new technology and systems. So the government's role as manager is a matter of choice, not necessity.

Quality Control - Contrary to government fears, there is a much greater incentive to improve quality and reliability than there is to "cut corners." This motivation is particularly strong in an area like space where performance and reliability are obviously of paramount concern to the customer, where performance is easily observable, where the customers are very well informed and where the product volume is small. Failures in space are very visible. If a commercial space company does not maintain a reputation for the highest possible reliability, it will very quickly cease to be a part of the industry.

With industry bearing the risk of failure, as it would with commercial procurement, it simply makes financial sense to invest substantially in improving product reliability. The government role in developing quality control procedures in the early days of rocket and space technology development was vital in establishing the enviable reliability track record of U.S. launch systems and spacecraft. But government procurement oversight now actually impedes the implementation of reliability enhancing improvements, owing to the bureaucratic and regulatory maze that has developed over time.

Financial Resources - It is a standard commercial practice to be sure that the supplier of a critical capability has the financial resources necessary to fulfill its contractual obligation. The government, when contracting for commercial space services, can and should assure itself that the supplier has the financial resources to deliver what is promised, and that the government has adequate recourse if it does not. However, this certification should be conducted in a manner consistent with the actual risk to the government. If the government does not pay for services until they have been rendered, there may be little risk. Any unnecessary reporting and documentation requirements imposed by the government simply raise the cost of the service or product to the government and discourage potential suppliers.

Industry regularly handles investments of the magnitude of those involved in space systems. The design and development of new commercial aircraft and engines, refineries, manufacturing complexes, pipelines, and communications networks can all be billion and multi-billion dollar commitments. Whether or not resources of this magnitude are available for private investment in space is strictly dependent on the nature of the commitment by the prospective customer(s). In many areas of commercial space endeavor the government will be a lead or dominant customer for some time to come, to support civil science and national security objectives. To the extent that the government is willing to make hard commitments to use services or facilities when they become available, then the financial resources to construct and operate them are likely to be available. Few companies are willing to bet much on the current year-to-year appropriation process.

Recourse - Many contractual tools are available to ensure performance or provide recourse in the event of failure. These techniques include: source qualification, performance incentives and penalties, bonding, performance milestones, requirements for specific performance, and assignment of interest in case of failure. In contracting for commercial space services, the government can negotiate a combination of provisions which create the strongest incentives for success and best protect the government's interests.

The Committee's three primary conclusions concerning industry reliability are:

1. **Industry is fully capable of designing, developing and operating space systems to support all or most of the government's operational requirements.**

2. **Standard commercial contracting procedures can provide adequate protection to assure the successful and timely completion of required space projects.**

3. **The use of commercial contracting by the government for space services is dependent on the government's ability to make reliable contractual commitments.**

E. Benefits to Government

In addition to general benefits to the economy, other direct benefits to the government from expanded commercial space operations include:

Lower Costs - There are several factors which will allow lower costs for commercially supplied space operations support. Commercial-style procurement will eliminate the substantial "overhead" cost of doing business with the government using current procurement practices. Private industry can more easily make up-front investments to reduce long-run operating costs than government programs funded in the traditional manner, particularly in the current, highly constrained budget environment. The development of competitive market environments for space operations will create continuing pressure for innovation and cost reduction. By reducing its role as owner/operator of hardware systems, the government will be able to take advantage more rapidly of improved technology as it becomes available (by switching suppliers).

Wider Range of Space Goods and Services -A competitive market environment is more likely to generate alternative approaches and differentiation of service offerings than a government managed process. Government program planning and budgeting tends to force consolidation of approach in the name of economy. For example, commercial launch service operators are fielding vehicles of many different sizes and technologies. This will give government program managers increased opportunities for launch and the ability to trade off cost, reliability, availability and payload size as appropriate to their programs. The government approach was to produce one system (shuttle) to launch everything.

Reduced Technology Development Expense In the current environment the government pays for most space technology development. If a significant portion of the government's operational space requirements were fulfilled on a commercial service basis, it would create a stronger incentive for private companies to support technology development to improve their competitive positions for such service contracts. The government would still maintain its role in supporting longer range, advanced technology development that is beyond the private sector's ability to support. Thus, commercial space service procurement by the government will expand the range of justifiable investment in technology development, allowing the government to concentrate its resources on advanced technology development where its dollars have more leverage.

Reduced Upfront Costs - If the government becomes a reliable commercial customer for space services, then upfront capitalization of some space systems could be transferred to the private sector. The government contracts would support conventional project financing or justify corporate investment. Reducing the budget "bulges" associated with new hardware program starts will allow increased government program continuity in areas whose funding has been hit to support the upfront costs of new hardware systems. By offering reliable contracts for the future purchase of space services, the government will be able to defer some near-term expenditures, which will help address the current budget deficit.

Shifting of Risk to Private Sector - By moving to a commercial procurement mode, the government need not pay for services until they are rendered. If the government defines clearly in advance the services it requires, it can and should require firm fixed price contracts. In a commercial service mode (as described in Section IV-A), the supplier bears most of the cost, technical and schedule risk. This approach gives the government greater certainty about future costs, which will help reduce the budgetary havoc caused when programs experience "cost growth."

F. Benefits to Industry

Successful implementation of the approach proposed above would create important benefits for existing and prospective commercial space ventures:

Reduction in Unmanageable Risks - Operating as a commercial service provider to the government rather than a traditional government contractor imposes the burden of cost, schedule and technical risks on the provider. From industry's perspective, it is preferable to accept risks and responsibilities which it can manage, rather than trying to deal with the unmanageable risks associated with current government procurement practice.

Larger Near-Term Markets - To the extent that the government's routine, operational space requirements are presented to the market as commercial demand, it could substantially increase the size of the current markets for space goods and services. For example, the projected market for commercial launch services would triple, if all government meteorological, communications, navigation and scientific satellites (which do not require the shuttle) were added to the demand for commercial communications satellites.

Wider Range of Space Goods and Services - For commercial space ventures which depend on transportation or support services, the development of competitive markets in space goods and services will expand the range of service offerings. For example, several proposals exist to offer reentry vehicles that would provide sample return for material processing experiments. This would allow earlier and more frequent access to space for materials experiments that do not require manned intervention.

Improved Access to Capital Markets - Government purchasing of space goods and services on a "commercial" basis would greatly improve the funding potential for these ventures. Firm commitments of this kind would make potential investors more willing to participate on both equity participation and debt financing bases.

Better Positioning for International Competition - Private, commercial development of space systems should yield lower cost and quicker development cycles. Commercial developers can also respond more quickly to changing market requirements. Experience with the commercial launch service industry thus far is that the cost burden of government documentation and in-process inspection requirements is about 25% of the total cost.

Improved Technology Diffusion to Other Industries - One of the ways that commercial space operators will seek to manage the risk of their programs is to seek alternative applications of technologies they develop. Any revenues generated by licensing or direct application to other products helps to reduce the financial exposure and risk of the space venture. This creates an economic incentive to get the maximum possible return from new space technology developments. Also, the expansion of commercial space activity will encourage more non-space companies to examine the existing store of government-sponsored technologies for possible applications.

G. Conclusion

The Committee believes that private industry is capable of fulfilling many of the government's operational space requirements on a commercial basis. That is, the government should be able to rely on industry to competitively design, fund and operate space systems to support government space activities. To achieve this the government must be able to clearly define its operational requirements and make reliable commitments to purchase services which satisfy those requirements.

Because of the benefits that will accrue to both the government and industry, the Committee believes that the government should commit itself as a matter of law to procuring commercially supplied space goods and services. This implementation of existing national space policy must be carried out in a thorough and consistent fashion, including modification of government procurement statutes and regulations as necessary (see Recommendations in Section VI).

To some observers, the relationship recommended here may seem to be a modest change from the current pattern of government contracting. *In fact, successful implementation would constitute a very fundamental realignment of the relationship that has prevailed, particularly in civil space activities, between government and industry.* The recommended relationship would put greater responsibility and burden of risk on the private sector in return for the authority necessary for efficient management. It would allow greater flexibility and innovation by the private sector in meeting government needs.

This approach minimizes the disruptive influences of government on market development and supports maximum competition and innovation. The approach matches the respective strengths of government (market for advanced technology, supporter of long-term R&D) with the strengths of industry (incremental innovation and cost reduction). In doing so, the approach begins to parallel successful government/industry collaborations in the past, most notably in the development of the aviation and nuclear industries.

V. Summary Of Conclusions

1. Commercial development in space is vital to future U.S. leadership. Space offers potentially unique opportunities for economic growth and revitalization of existing industries. A robust space industrial base supports other national objectives: national security, international relations, exploration and scientific advancement.

2. Economic competition in space will become increasingly intense. Foreign space programs are more heavily focused on potential commercial applications. The strategic significance of space (commercial, military and prestige) has motivated other countries to make substantial commitments to develop national space capabilities. This commitment includes subsidization of "commercial" space services.

3. The competitive position of U.S. industry in space-related business has eroded badly. While U.S. military space technology is still preeminent and considerable resources have been committed to the U.S. manned space program, support for continuing space science and technology advancement has been erratic, and technology diffusion to industry has been impeded.

4. U.S. government policy and programs to encourage commercial space development have been unstable. A critical problem facing U.S. companies interested in space has been the unpredictability and unreliability of the government in priorities, program funding and the policy process affecting potential space ventures.

5. True commercial competition to fulfill U.S. government space requirements would efficiently stimulate private investment and innovation in space. "True commercial competition" does not mean simply shifting additional risk to the private sector within the existing government/industry relationship. Rather, commercial supply of space services would constitute a major reallocation of risk and responsibility between government and industry. Industry is willing to accept greater risk and responsbility in space development only to the extent that it has the authority, flexibility and increased profit potential to justify it. Significant benefits should accrue to both government and industry from this new relationship.

VI. Recommendations

Consistent with the recommended relationship between government and industry in space development and the requirements industry has to fulfill its role, the Commercial Space Advisory Committee identified 16 specific recommendations for the government to more efficiently support commercial space development. The Committee is confident that successful implementation of these recommendations will result in:

- increased private investment and innovation in space
- quicker, more efficient realization of the economic potential of space
- improved U.S. competitive position (both directly in space industries and indirectly through secondary use of space technology in other industries)
- lower cost to the government and greater operational flexibility to fulfill government space requirements.

The recommendations are grouped in relation to the government's organization and the many roles it has which affect space business. The recommendations are not arranged by priority.

A. Government Organization

From industry's perspective, the government has not demonstrated a clear commitment to commercial space development, nor an organizational focus or agreed approach which might give stability to the nation's space efforts. Furthermore, there is little evidence of a constructive dialogue--particularly between the Executive and Legislative Branches--which might develop such agreement and stability.

Recommendation #1: Presidential & Congressional Commitment - Develop strong, visible Presidential and Congressional support for commercial space development.

The President and Congress must forge a non-partisan consensus on how the country can most effectively pursue commercial development in space. The agreed approach must be enunciated in Presidential policy and implemented in agency directives and, where appropriate, public statutes. The current national space policy represents a useful starting point in establishing goals, principles and interagency relationships, but many implementation details remain. Only a clearly delineated approach and demonstrated Congressional and agency concurrence will begin to create the confidence necessary within industry to expand private risk taking in space. Visible evidence of Presidential and Congressional interest and support increases program funding stability, speed and continuity in agency implementation and bargaining power in international trade negotiations.

The elements which the Committee feels must be included in the approach and its implementation constitute the remaining recommendations.

Recommendation #2: Single Cabinet Level Focal Point - Designate a single Cabinet level official as the focal point for policy advocacy, program management and budget authority for commercial space development.

The government lacks a clear and comprehensible focus for commercial space issues. Multiple agencies are involved in poorly defined, and sometimes conflicting, ways on issues of concern to industry. This frustrating and inefficient situation could continue indefinitely without a clear designation of leadership on the issue.

The first aspect is policy advocacy and coordination. One must recognize that even with a strong, Presidential commitment to support commercial space development, legitimate policy conflicts will arise where national interests and priorities must be balanced. The final forum for addressing such policy disputes is the Cabinet. Commercial space development must have a clear advocate for national economic interests vis a vis national security, foreign policy and other concerns. The designated Cabinet official must have minimal agency interests or responsibilities which would conflict with such advocacy.

The designated Cabinet official would also be responsible for developing an effective, nonpartisan consensus with Congress and assuring continuing cooperation. Many of the Congressional oversight and appropriations subcommittees currently involved in commercial space issues lack expertise in the business issues affecting space commerce. The designated cabinet official should move immediately to highlight the many and diverse effects that government actions have on business decision making regarding prospective space ventures. This focus should facilitate a better informed public debate.

Policy, program and budget must be tied together. The various government programs intended to support commercial development must be rationalized to improve consistency and continuity, and to avoid duplication of efforts. The Committee recommends that this be accomplished by vesting in the designated Cabinet official program management and budget authority for programs directly related to commercial space development.

The issues of concern here are the business issues of space. It is assumed that NASA and DoD counterpart agencies will continue to provide leadership in technical issues, and their expertise will be drawn on appropriately by the designated Cabinet official.

Recommendation #3: Forum for Industry Views - Establish a permanent industry advisory committee representing all space industry sectors to advise the designated Cabinet official.

Because of the dominant role government has with respect to commercial space development for the foreseeable future, careful government/industry coordination is critical. The Committee recommends that an ongoing industry advisory committee be created to advise the lead Cabinet official on all matters affecting the development of commercial space industries. It should be chaired by and composed entirely of representatives of U.S. private industry.

The proposed permanent industry advisory committee would report to the lead Cabinet official, who would then represent the interests of U.S. space industries in government policy formulation and international negotiations.

The committee should be chartered to initiate its own monitoring activities of government activities as they affect industry development, rather than reacting only to requests for advice. No policy or program decisions affecting commercial space activities should be effected without review and advice from this Committee. These arrangements will help insure greater continuity in the government's many roles affecting space businesses.

Recommendation #4: Clear Definition of Executive Agency Roles - Define clearly how various (e.g., regulatory) government agencies will execute their responsibilities concerning space businesses.

While the Committee recommends that the functions and authorities described above be centralized in a single Cabinet official to provide better leadership, it recognizes that many Government agencies have statutory authority and organic functions which affect space business (e.g., regulation for public health and safety, adherence to international obligations and the like). The more quickly such agencies define and simplify how their responsibilities will be exercised and how the roles of related agencies are differentiated, the easier it will be for commercial space ventures to proceed.

The earlier proposal to establish a lead Cabinet official was not intended to create a "superagency" for commercial space activities. Indeed the role space plays (and commercial space operations might play) is too pervasive already to allow complete centralization. However, clear definition and centralization of certain key roles will allow more effective leadership and coordination, including coordination with agencies whose missions affect commercial space ventures in some way.

B. Government Roles

The government has many roles which affect commercial space activities. The Committee elected to focus on six which have critical effects in shaping the environment for space business decision making: 1) liability exposure, 2) guarantor of a level playing field, 3) research and development, 4) customer for goods and services, 5) service provider, and 6) regulator. In the fulfillment of public responsibilities affecting space development, the government should be concerned about "how" it proceeds. Latitude often exists to achieve desired public objectives in minimally intrusive ways, or to reduce risk for commercial space operators (thereby encouraging investment) in ways that do not create incentives for inefficient behavior.

None of the recommendations below constitutes a proposal for "special treatment" for space industries. Many are appropriate for high technology economic development generally. *The recommendations here are an attempt to blend together public and private objectives in the most efficient way possible to assure the long-term competitive position of the U.S.*

Liability Exposure

Recommendation #5: Excess Liability Insurance Coverage - The government should accept liability for commercial space activities beyond the level of liability insurance which is commercially available at reasonable rates.

Liability exposure is becoming a problem for many industries, both high tech and traditional. The differences between how this issue is handled in U.S. versus international competitors is introducing distinct (and in some cases, insurmountable) competitive disadvantages for U.S. companies. Most indications at the moment are that this problem will only get worse. Industry executives cannot afford to "bet the company." If U.S. companies are forced to walk away from new products or services, but foreign competitors are protected by their governments, this imbalance could be economically devastating for the U.S.

Space poses some particular problems in terms of liability insurance coverage. Space is a relatively new area of activity, hence the actuarial experience base is very limited. Even as space matures, the number of insurable events will remain low in statistical terms, making it difficult to estimate risk and calculate rates. Space also offers the possibility, however remote, of a catastrophe. These factors make it difficult for the insurance market in the near term to provide adequate liability coverage.

The approach recommended here addresses the problem of having to "bet the company," if liability coverage for very low probability events is not available, while still maintaining an incentive for commercial operators to reduce the risk inherent in commercial space systems. As commercial space activity expands, this government role may become unnecessary. By providing for coverage beyond what the market can provide (rather than establishing a fixed ceiling), this approach allows a smooth transition or phasing out of the government role as private insurance capacity expands and potential liability risks become better understood. It should be noted that this proposal relates only to excess liability (i.e., potential second and third party damage) exposure rather than product insurance.

This recommendation does not constitute a "direct subsidy" to industry. Market forces will maintain a strong pressure to reduce system costs and improve reliability. Any reduction in risk is likely to reduce insurance costs, allowing a more competitive price for the space good or service. In addition, the government (through its regulatory powers) can assure that all reasonable measures are taken to minimize the risk of second or third party injury.

However, it is not possible to design systems for space or anything else that have absolutely no risk of failure. The issue is to assure that the risks are acceptably small given the value being generated and that incentives and controls are instituted which will assure that risks are maintained at the acceptable level or reduced over time. The likelihood of the government incurring any costs through this proposal is extraordinarily small. There are sufficient benefits (both economic and national security) to the government from the development of commercial space operations to justify this commitment. The primary effect of the proposal is to establish a finite bound for the risk to which a private company is exposed, while not interfering with market development in the space insurance industry, nor creating incentives for less safe systems.

The other issue to be addressed in liability insurance is really a trade issue. If other governments accept the liability risk directly for their commercial space operators, or cap the liability for customers at very low levels, then this will give foreign space system operators a cost advantage over U.S. operators. The issue of the government's role in liability insurance is one of many which must be covered by "rules of the road" trade agreements (described below).

Recommendation #6: Tort Reform - Enact appropriate tort reform proposals to create better discipline and predictability to commercial risk.

A related issue concerning the potential financial exposure for U.S. space business is the increasingly unbounded and inconsistent pattern of damage awards in U.S. litigation. This situation creates both an increasingly difficult problem for U.S. business people and an increasing competitive advantage for foreign competitors. The uncertainty of potential space business operations is compounded by the utter unpredictability of the damages which might be awarded in the event of accidents.

It should be possible to develop a fair and reasonable balance among the different interests involved, without exposing business decision makers to risks that are impossible to estimate. If progress toward tort reform cannot be made in Congress soon, the U.S. will pay an increasing price in lost jobs.

Guarantor of a "Level Playing Field"

Recommendation #7: Trade Strategy- Develop a U.S. government strategy to promote the creation of a fair trade environment for space goods and services.

One of the key requirements described above to support U.S. commercial space development is the creation of a fair international trade environment for space goods and services. This will not be easy, as the motivations for foreign governments to subsidize and protect their nascent industries will be strong. Foreign national support may be stronger in space than in any other area of coming economic competition, given the projected long-term economic potential and the shorter term national security and prestige benefits.

Past attempts to create enforceable fair trade agreements have been notably unsuccessful, where a strong enough motivation exists for a trading partner to continue its unfair trade practices. Developing a fair trade environment for space is therefore extremely difficult, but an absolute necessity for U.S. industry.

Rather than pursuing sectoral trade agreements on an ad hoc basis for different space sectors, the designated Cabinet official should take the U.S. government lead in developing an overall space trade strategy. Industry input for the development of this overall strategy should be provided by the permanent space industry advisory committee proposed above, to assure that the interests of all industry sectors are treated consistently. This strategy should lay out principles and objectives that can be applied consistently across all space business sectors. It should identify new enforcement provisions, examining a wider range of methods to apply pressure for fair trade. For example, the latest national space policy calls for reviews of the trading practices of other space-faring nations when considering possible cooperative space research projects with them.

The U.S. bargaining position in space is strongest now (given the relative size of the U.S. market for space goods and services and the relative technological strength of the U.S.) and should be exploited.

Recommendation #8: Trade Negotiations -Negotiate and enforce trade agreements guaranteeing fair trade for all space industry sectors.

Once a consistent strategy has been developed which exploits U.S. strengths and linkages among space sectors, the U.S. government should take an active lead in developing fair trade agreements for space. The Committee recommends that lead responsibility within the U.S. government to pursue space trade agreements be one of the primary activities of the designated Cabinet official for space commerce.

Space trade agreements could be developed bilaterally or multilaterally, as circumstances dictate. The rate of progress will depend on the state of maturity of each industry sector; as each sectoral agreement is achieved, consistent with this country's basic goals and principles for space trade, it sets a precedent for later agreements in other sectors.

The key to long-term success in this area lies in the identification and implementation of effective enforcement mechanisms.

Recommendation #9: Intellectual Property Rights - Lead the development of an international agreement to protect intellectual property rights in space.

Patent law and process is territorially based. Necessary translations need to be developed for space to assure adequate protection for processes developed and products made in space. Some progress has been made in this regard in the negotiations on the international space station. This work can be built on to develop a general international agreement.

Research & Development

Recommendation #10: Space R&D Leadership - Maintain an aggressive, broad-based basic science and advanced technology development program for space.

The U.S. has not maintained a stable program to advance space science and technology development. Numerous areas where discontinuities exist have been highlighted in reviews by NASA's advisory committees and outside technical organizations. Some of the factors contributing to these discontinuities have been discussed above, including: budget cuts and uncertainties, diversion of resources from space science projects to support operational manned programs, lower priority in launch scheduling before the Challenger disaster, and compounding delays from the shuttle grounding. Uncertainty concerning funding and professional opportunities in space science has reduced the number of candidates seeking academic training in the field--an effect which may take many years of stable support to overcome.

It is vitally important that an aggressive, broad-based space "technology push" program be maintained - in parallel to, and not exclusively dependent on manned space operations. It is the advancement of fundamental space science and technology which is most directly beneficial to commercial exploitation. Although attempts have been made recently to improve funding levels for technology development, the primary orientation for most of the new technology programs is manned space operations. The technologies pursued to further manned space are not productive for application to commercial space, which is predominantly unmanned. Thus, there needs to be some broadening of research objectives to embrace more than advancing manned space objectives. Previous discussion in this report noted both the powerful prestige implications of manned space activities and the fact that priority commitment to this approach is, of necessity, a political decision. Given the commitment to manned space leadership, steps can nonetheless be taken to improve continuity and productivity in space science and advanced technology programs.

To improve stability, funding for space science and advanced technology programs (both manned and unmanned) should be segregated to the greatest extent possible from operational programs, and funding commitments must be made on a multi-year basis. Projects managers should be given as much individual latitude as possible to select the best means to accomplish project objectives, including selection, as appropriate of manned vs. unmanned systems. Reliance on commercial space services, as dictated in national space policy, may offer quicker, lower cost ways to achieve research objectives. Implementation of this policy directive will occur more effectively if individual project managers are free to explore such alternatives.

NASA's programs to encourage cooperative R&D ventures (with universities and industry), while recently over-focussed on manned applications which have been NASA's principal thrust, help to decentralize and broaden interest in space. They also leverage government research dollars. These programs, and efforts to engage other government agencies with potential interest in space, should be encouraged and expanded.

The aggressiveness of the U.S. space R&D program is dependent on both the stability of the program and the level of funding it receives. The leverage offered by space technology (discussed above) makes a long-term stable and increased commitment in this area a matter for serious national consideration, even in the face of severe budget constraints.

Recommendation #11: Technology Diffusion - Facilitate the transfer of government-developed space technology to the private sector for commercial exploitation.

Continuing government attention must be directed at the issue of technology diffusion. The U.S. is still preeminent in most areas of space technology. It is in the area of commercial application where the U.S. has lost the most ground, in relative terms. Clearly something has been missing in the U.S. approach to translating government research to commercial products.

A recognition has developed in recent years that government policies concerning the rights to technologies developed under government contracts were impeding the commercial application of some of these technologies. Concern about losing commercial rights inhibits some companies from seeking to develop innovative technologies (which might be useful to the government) under government contract.

Some progress has been made, in the form of the Federal Technology Transfer Act, Executive Order 12591, and attempts to develop innovative contracting procedures. These reforms, among other things, allow retention of commercial rights (while protecting the government's interests), thus easing the commercial utilization of technologies developed by government employees or contractor employees at government laboratories. Current national space policy specifically directs all governmental space agencies to: "Provide for the timely transfer of Government-developed space technology to the private sector in such a manner as to protect its commercial value, consistent with national security."

The issue of technology diffusion should be pursued on several fronts to assure the most efficient possible flow of government generated space technology to commercial application. Both overall government policy and individual agency implementation should be reviewed in relation to the terms and conditions (such as patent provisions) used in government procurement and access to federal research facilities and researchers. While most space technology is sensitive from a national security standpoint, every effort should be made to allow commercial utilization of this technology. Finally, efforts should be expanded to develop innovative approaches to collaborative R&D ventures among interested government industry and academic organizations

Recommendation #12: International Cooperation - Maintain scrutiny of international cooperative ventures to assure that U.S. economic interests are protected.

International cooperative activities in space serve several national objectives, including foreign policy and scientific development goals. Current policy states that the United States will seek "mutually beneficial international participation in its civil space and space-related programs." It further states that such activities will "...be conducted in such as a way as to protect the commercial value of intellectual property developed with Federal support. Such cooperation will not preclude or deter commercial space activities by the United States private sector, except as required by national security or public safety."

The policy fails to establish a process by which such cooperative ventures will be examined for "mutual benefit," except to call for interagency review. In the face of increasingly stiff economic competition, the government must recognize that international cooperative projects in space (and in fact all cooperative science and technology agreements the U.S. enters into) involve trading in a highly valued commodity: technical knowledge. Explicit consideration should be given in considering such agreements to balance foreign policy gains (goodwill) vs. potential economic losses.

The designated cabinet official should ensure that an appropriate review process is instituted to maintain a proper balance of national interests. Except in extraordinary circumstances, the guiding rule should be that all parties to such agreements benefit (in scientific and technological exchange) in equal measure to their contributions. The review process for such agreements should be permanently institutionalized to assure long-term adherence and continuity.

Customer for Commercial Space Goods & Services

Recommendation #13: Purchase of Commercial Space Services - Implement current national space policy committing government to purchase commercially available space goods and services to the fullest extent feasible.

Current national space policy creates a framework for an efficient and constructive relationship between government and industry in space by directing government space agencies to purchase commercial space goods and services. Offering government demands on commercial terms is one of the most effective means government has to stimulate private investment and innovation in space, the benefits of which were described above. However, few visible steps were taken to implement the policy. The policy should be confirmed by the new Administration with detailed agency guidelines on how it is to be observed in agency program planning and procurement actions.

One of the key requirements for successful implementation is creation of procurement standards (by statute and regulation) which will allow commercial style procurement. Conditions under which this can be done are very limited at present, and in particular do not address the situation contemplated in policy: prospective commercial supply, rather than an already demonstrated commercial market. Under leadership of the designated cabinet official for commercial space, the Office of Management and Budget (which oversees federal procurement practice) and interested agencies should work with Congress to define new procurement standards to emulate commercial practice to greatest extent possible. Adequate contractual means exist to protect the government's interests, as described above in Section IV-D.

For the government to benefit from commercial style procurement, it must implement mechanisms by which it can make reliable future commitments.

Recommendation #14: Government/ Industry Competition - Implement current policy to minimize conflict between government and commercial space operations.

Current national space policy calls for the government not to preclude or deter commercial space enterprises, and specifically not to engage in potentially commercial space operations so as to preclude or deter, except for national security or public safety reasons. The designated cabinet official should work with other departments to generate for industry a clear definition as to which activities might fall within this category, and a process by which to quickly, fairly resolve any conflicts which might arise.

It should also be noted that as commercial space activity expands, an increasing range of space-related facilities may become reasonable commercial propositions, including facilities which have traditionally been built and operated by the government. It is important that a process exist for resolving potential conflicts of this kind, to assure continuity and minimize the kind of friction which has occurred during the last few years between government and commercial activities.

Service Provider

Recommendation #15: Access to Facilities - Assure equitable access to government space facilities on an incremental cost reimbursement basis.

Certain facilities necessary for space operations are beyond a reasonable investment threshold for the private sector. In some such facilities which have been established to support government operations, excess capacity exists. Current policy for government facilities, in general, and the space policy in particular call for such facilities to be made available on a direct reimbursement basis. Such facilities include both operational (e.g., launch and range control, tracking and communication) and research facilities (e.g., computational facilities).

Assuring equitable, "incremental cost" access to such facilities (with minimum complications and uncertainties) is a vital foundation to expanding private sector investment in space and is more consistent with the cost basis of services offered by international competitors.

Regulator

Recommendation #16: Regulation - Define efficient and stable regulatory procedures to govern commercial space operations.

The government has a variety of public responsibilities to fulfill in relation to current and prospective commercial space activities. The responsibilities, fulfilled through regulatory oversight, include: public safety, adherence to international treaty obligations, preventing adverse technology and data transfer, allocation of limited resources (such as orbital slots for communication satellites). These represent necessary functions, and some are very desirable from industry's standpoint to support efficient operations. What is of concern to industry is how these responsibilities are fulfilled, in terms of timeliness, stability, receptiveness to industry input, and attention to the costs imposed on industry to fulfill regulatory requirements. The designated cabinet official should conduct a review of required regulations to see that they are simplified to the greatest extent possible.

Given the current uncertainty and complexity of the business environment for space activities, the designated cabinet official can play a valuable role simply by providing a "single point of contact" for industry, where all of the regulations and procedures affecting potential ventures are identified. Where appropriate the designated official should act as an ombudsman for industry with regulatory agencies to ensure timely response.

The proposed industry forum could serve in a review capacity and the designated Cabinet official could act as an advocate where industry feels regulatory procedures are unduly costly or burdensome.

SPACE COMMERCE
AN INDUSTRY ASSESSMENT

FOREWORD

The commercial development of space is vital for maintaining U.S. economic competitiveness. Space is a challenging new place to do business, creating new industries and new jobs. Advanced space technologies can also be employed in traditional industries to enhance productivity. Space further serves as a powerful catalyst for new science and education offering breakthroughs in many disciplines and motivation for better technical education.

President Reagan's National Space Policy and Commercial Space Initiative, announced in February, recognize the importance of a strong commercial space sector. As space technology continues to mature, the international competition to apply that technology commercially becomes increasingly intense. The President's policy has redefined the relationship between the government and industry to meet that competitive challenge. Greater reliance on private sector investment and innovation is critical to U.S. leadership in space.

The government has been the dominant player in space. However, it is important to remember that commercial space development is not a government program--rather it is dependent on private investment. The Department of Commerce's role is to help remove impediments to private investment in space-related goods and services.

This report is intended to provide improved information for business decision-makers. It is the first in a series of space industries assessments. These assessments will provide objective, up-to-date information, helping U.S. industry and financial institutions to better assess commercial space opportunities. I encourage your comments and suggestions for future reports.

C William Verity

C. William Verity
Secretary of Commerce

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INTRODUCTION

The prospect of doing business in space has been discussed for many years. Today, it is a commercial reality. The direct economic benefits already have been demonstrated in space transportation, satellite communications, and remote sensing markets. The indirect benefits have been equally significant. Space-related technologies applied to earth-based industries have resulted in new and innovative techniques and processes that improve the quality of production. Additional areas of economic potential will develop with the establishment of space-based facilities and further research into materials processing in space. Entirely new and unforseen space markets are likely to emerge as man's activity in space increases.

This report identifies existing and potential worldwide markets for space-related goods and services, focusing on five major areas: (1) Space Transportation, (2) Satellite Communications, (3) Satellite Remote Sensing, (4) Space-Based Industrial Facilities, and (5) Materials Research and Processing in Space. The report also examines aspects of Insurance and Finance relevant to commercial ventures in these markets. Finally, the report presents assessments from U.S. industry representatives on their ability to compete against foreign competition in each of the five major areas.

(1) Space Transportation, which is the foundation for space-based activities, is a rapidly growing industry. Commercial launch services range from sub-orbital sounding rocket flights for microgravity experimentation to the use of powerful, multi-stage vehicles for placing communications satellites and other large payloads into earth orbit and beyond. This is an intensely competitive international market, involving U.S. commercial launch-service providers and entities from a growing number of industrialized nations. Europe, the People's Republic of China, and the Soviet Union are all marketing launch services. Japan will soon be a competitor. Support services, such as payload processing, are also developing into profitable operations, and commercially operated spaceports are being planned in the United States and abroad.

(2) Satellite Communications is the most developed area of commercial space activity. Satellites are a vital element in the global telecommunications network, permitting communications between points on land, sea, and in the air, as well as instantaneous communications on a worldwide basis. More than two-thirds of the world's international voice communications and virtually all of the world's video programming are transmitted by satellite. Almost all of the countries in the world are members of at least one international satellite organization, and the number of countries with dedicated satellite systems continues to increase. Like the provision of satellite services, the manufacture of spacecraft and ground segment facilities is a multi-billion-dollar-a-year industry. In addition to U.S. companies, European, Japanese, and Canadian manufacturing firms are becoming increasingly competitive. Further, a substantial infrastructure of enterprises -- such as satellite-capacity resellers, domestic and international teleports, and

other equipment and service providers -- has developed to support the satellite industry.

(3) Satellite Remote Sensing, a technique for measuring the properties of earth from space, is a rapidly expanding commercial enterprise. The United States, France, Japan, India, and the Soviet Union all have commercial remote sensing satellite systems in operation. The European Space Agency, Canada, Brazil, and China also have announced plans to launch such systems in the early 1990s. The data collected by remote sensing satellites is used in such activities as mineral exploration, agriculture, fishing, forestry, environmental monitoring, and land-use. The fastest growing segment of this industry is the value-added product and service component, which consists of manufacturers of computer hardware and software for analyzing remote sensing data and companies that interpret the data and integrate it with other data bases to produce analytical and predictive products. There are more than 175 value-added companies in the United States and an additional 125 operating throughout 24 other countries worldwide. The number of value-added companies has increased from two to three times during the past 10 years.

(4) Space-Based Industrial Facilities range from relatively simple platforms to fully equipped orbiting laboratories capable of supporting manned operations in a shirt-sleeve environment. They may be used for scientific research, technology development, satellite assembly and servicing, and materials processing. The Soviets have maintained such facilities in orbit on a near continuous basis for the past 20 years. The European nations have already developed several space-based facilities for use with the Space Shuttle and are currently developing facilities that can remain in space on a permanent basis. A number of U.S. companies are also establishing such facilities on a commercial basis.

(5) Materials Research and Processing in Space (MRPS) is the least developed market, but it is one of the most promising. MRPS involves exploiting the microgravity and high vacuum characteristics of space. Experimentation in this area has already led to significant advances in materials science, improved ground-based production methods, and other industrial applications. Continued MRPS research and experimentation might even result in commercially viable products, now unknown, that are uniquely suited to space-based production. Potential MRPS products include pharmaceuticals with higher purity than can be achieved on earth, crystals that can be used to facilitate the design of new drugs, better semiconductors and other electronic devices, and higher strength alloys. The commercial potential of MRPS has not gone unnoticed. The Europeans, Japan, China, and the Soviet Union have all engaged in major MRPS programs aimed at future economic growth opportunities.

Each of the five areas described in this report is divided into market segments, based on the type and variety of space goods and services to be provided. In each segment, the suppliers of such goods and services are described on a country-by-country basis, and the anticipated demand is identified.

During the past year, the Department of Commerce held meetings, briefings, and one-on-one discussions with industry representatives from aerospace and non-aerospace companies, Fortune 500 companies, and entrepreneurs to determine what they perceive to be the primary impediments to their ability to compete in the increasingly intense international space markets. These impediments were virtually identical across the entire range of space activities. The market and financial impediments cited were: (1) uncertain demand, (2) lack of reliable access to space, (3) high capital costs, and (4) long payback periods.

Most impediments cited also involve legal, policy, and institutional factors that can only be addressed by the U.S. Government. Specifically, these impediments include: (1) U.S. industry's inability to compete, on a commercial basis, against the offering of space goods and services at rates subsidized by the U.S. Government or foreign government-backed entities, (2) traditional government procurement practices that preclude companies from serving the U.S. Government and commercial and foreign customers from the same production lines at lower production costs, (3) industry's difficulty in gaining access, on commercially reasonable terms and conditions, to U.S. Government facilities required for conducting space activities, and (4) no clear and comprehensive national space policy coupled with a Government commitment to long-term stability on which U.S. industry can build its business plans and investment strategies.

The President's new National Space Policy and Commercial Space Initiative represent a broad policy framework for addressing these challenges on a long-term basis. The policy attempts to define, clearly and concisely, the respective roles of the U.S. Government and the private sector in space activities. The projected effect of the new policy on Space Sectors is appropriately identified throughout the report.

I. SPACE TRANSPORTATION

Space transportation consists of the delivery of payloads to and from space, as well as the transfer of payloads between various earth orbits and points beyond. Routine, affordable, assured access to space is essential for conducting commercial activities in space, particularly industrial research and development that can lead to new space-based commercial applications.

BACKGROUND

Prior to the advent of the Space Shuttle, the U.S. expendable launch vehicle (ELV) manufacturers produced vehicles only under contract to NASA and the Department of Defense (DOD). Commercial entities would contract with NASA to launch their payloads, mostly communications satellites. NASA would purchase a launch vehicle through traditional government procurement practices, and the launch of the commercial payload would be conducted by private-sector contractors under NASA supervision.

Policies concerning the commercial use of ELVs and associated launch facilities and services originated with the Government's decision in the late 1970s to make the Space Shuttle the nation's only launch vehicle.[1] Government funding of ELV production ceased in 1983, after the Shuttle was declared operational. By that time, however, many recognized that the Shuttle, with a lower annual flight schedule and performance capability from what was originally planned, could not meet all of the national security, civil, and commercial launch requirements. Also by that time, the French launch company Arianesspace, with substantial backing from participating European governments, had begun to compete with the Shuttle for U.S. and foreign payloads. Several U.S. private firms expressed interest in producing and operating ELVs commercially. Through a series of Presidential Directives and Orders,[2] and the passage of the Commercial Space Launch Act of 1984, the Government endorsed the establishment of a U.S. commercial ELV industry.[3]

The Commercial Space Launch Act requires the Department of Transportation to facilitate and promote commercial space launches by the private sector. In carrying out this mandate, the Department of Transportation, among other things, is required: (1) to license and regulate launches of space vehicles and the operation of launch sites by persons within the jurisdiction of the United States, consistent with public safety, national security, and international obligations, (2) to take actions necessary to make U.S. Government launch property and facilities available for commercial use, and (3) to determine the appropriate levels of liability insurance required by licensees under the Act.[4] Pursuant to these responsibilities, the Department of Transportation's Office of Commercial Space Transportation has issued licensing regulations for commercial launches,[5] and is developing procedures for determining appropriate levels of liability insurance.

The Government's endorsement of a commercial ELV industry was not without early contradictions. Even after the passage of the Commercial Space Launch Act, NASA continued to use the Space Shuttle as a powerful competitor in the launch service market. Moreover, despite a Presidential Directive for NASA to establish Shuttle prices reflecting full cost recovery for commercial flights after Oct. 1, 1988, the price adopted by the Government was generally recognized to be below full cost recovery.[6] In contrast, U.S. space policy prohibited Federal subsidization of commercial launch services provided by U.S. companies. U.S. companies stated that they could not compete under these conditions.

The issue concerning subsidized pricing was formally raised by Transpace Carriers Inc., a U.S. company attempting to market launch services on the Delta ELV. Transpace initiated a complaint against Arianespace for unfair trade practices under Section 301 (a) of the Trade Act of 1974.[7] The complaint was ultimately dismissed, however, because the European government backing of Arianespace was found to be no greater than U.S. Government backing of the Space Shuttle program. As a result, the government-supported pricing of Space Shuttle and Ariane ELV services eliminated any prospect of U.S. private sector entry into the commercial space transportation market.

The Challenger accident in January 1986 led to the immediate recognition that the United States would be without access to space for a considerable period of time. A subsequent review of U.S. capabilities and payload requirements resulted in a determination that a mixed fleet of Shuttles and ELVs was required to provide the United States with assured access in the future. In addition, it became clear that the Shuttle, with further reductions in annual flight schedules, could not by itself support the growing backlog of high-priority national security and civil missions, much less the commercial and foreign payload requirements.

The President determined that one way to stimulate production of ELVs was to eliminate the impediments to a commercial space transportation industry, and particularly, NASA's provision of launch services at subsidized prices. On Aug. 15, 1986, the President directed that the Space Shuttle would no longer provide launch services for commercial and foreign payloads that did not require its unique capabilities, except for national security or foreign policy reasons.[8] As a result, the three large-capacity U.S. ELV manufacturers made corporate decisions to make large capital outlays and begin producing ELVs for commercial launch services. At least six U.S. entrepreneurial companies also began actively marketing launch services.

U.S. NATIONAL SPACE POLICY

On Feb. 11,1988, the President announced a new National Space Policy, the first comprehensive revision since 1982.[9] The main elements of this Policy as it applies to the commercial launch industry are:

- To require NASA and DOD, in consultation with the Department of Transportation, to make national launch property, facilities, and services available for commercial use, reimbursable at direct cost.

- To reinforce the existing policy prohibitions concerning commercial use of the Shuttle.

- To prohibit NASA from maintaining an ELV adjunct to the Shuttle.

- To require the U.S. Government to purchase commercial space transportation services to meet its requirements to the fullest extent feasible.

- To prohibit the U.S. Government from competing with or deterring U.S. commercial space transportation service providers. except for national security or public safety reasons.

- To require the U.S. Government to encourage international free trade in commercial space activities, and, when entering into space-related technology development and transfer agreements with other countries, to take into consideration whether such countries practice and encourage free and fair trade in commercial space activities.

- To require the Government to undertake research and development aimed at reducing the cost of space transportation and related services, to enter cooperative arrangements with industry to encourage private sector research and development, and to provide for timely transfer of Government developed space technology to the private sector, in a manner which protects the commercial value of the technology.

The World's Major Launch Centers

Country	Launch Site	Latitude	ELV Support Capability	Orbital Inclination	Status
USA	Cape Canaveral, Florida	28.5 N	All	Equatorial	Operational
USA	Vandenberg Air Force Base, California	34.7 N	All	Polar	Operational
USA	Wallops Island, Virginia	37.9 N	Sub-orbital/Small	Equatorial	Operational
USA	Palima Point, Hawaii	19.0 N	All	Equatorial/Polar	Planning Stage
Australia	Woomera Launch Facility	31.1 S	Sub-orbital	Sub-orbital	Operational
Australia	Cape York, Queensland	11.0 S	All	Equatorial/Polar	Planning Stage
Brazil	Alcantara, Maranhao State	2.0 S	Sub-orbital/Small	Equatorial/Polar	Under Construction
France	Guiana Space Center, Kourou, French Guiana	5.2 N	All	Equatorial/Polar	Operational
India	Sriharikota Launch Range, Sriharikota Island	13.9 N	Sub-orbital/Small	Equatorial/Polar	Operational
India	Thumba Equatorial Rocket Launching Station	8.0 N	Sub-orbital	Sub-orbital	Operational
Italy	San Marco, Kenya	2.9 S	Sub-orbital	Equatorial	Operational
Japan	Osaki Launch Site, Tanegashima	30.4 N	Sub-orbital/Small	Equatorial/Polar	Operational
Japan	Takesaki Launch Site, Tanegashima	30.4 N	All	Equatorial/Polar	Operational
PRC	Xi Chang, PRC	28.1 N	All	Equatorial	Operational
PRC	Shuang Cheng-Tzu	40.6 N	Sub-orbital/Small	Equatorial	Operational
Sweden	Esrange, Kiruna	68.0 N	Sub-orbital	Sub-orbital	Operational
USSR	Tyuratam	45.6 N	All	Equatorial/Polar	Operational
USSR	Plesetsk	62.8 N	All	Equatorial/Polar	Operational
USSR	Kapustin Yar	48.4 N	Sub-orbital/Small	Equatorial/Polar	Operational

U.S. INDUSTRY VIABILITY ASSESSMENT

The following section represents a distillation of current industry views on factors affecting the commercial prospects or viability of this industry sector. The industry concerns presented here have been expressed during the last year to the Department of Commerce through briefings by more than 100 companies covering the entire range of commercial space activities.

The views expressed here are those of space industry representatives and do not necessarily constitute policy recommendations by the Department of Commerce. This section is intended to provide a basis for more informed discussion of these issues. Where a diversity of industry views exists, an attempt has been made to present the various industry views in a balanced manner.

The success of U.S. industry in this market depends on a number of factors, some of which the launch companies can control, and others that are dependent upon the U.S. Government. Factors under the control of the commercial companies include investments made, risks taken, product quality/reliability, labor costs, production efficiency and marketing skills. The intent of the U.S. law and policy relevant to commercial space transportation is to provide a framework that will allow U.S. industry participants, without subsidy from the Federal Government, to be competitive with any other space transportation service provider in the world. Factors under the U.S. Government's control include the extent to which: (1) it makes its facilities available for use by the commercial companies, (2) it purchases commercial launch services instead of conducting its own, separate launch operations, (3) it is successful in promoting fair trade practices among foreign countries offering commercial launch services, (4) it works with industry in research and development and technology transfer, and (5) the extent to which it maintains a stable policy environment for long term business planning and growth.

Product Quality/Reliability

The Delta, Atlas/Centaur and Titan are highly reliable large capacity ELVs. Each has a success rate of more than 90 percent. By contrast, the success rate of the European Ariane ELV is approximately 82 percent.

Small capacity vehicles made in the U.S., except for the Scout, are untested; however some, however, are simply new configurations of boosters and upper stages used successfully over many years for Government programs. Others are the product of long-term R&D.

Availability Of Government Facilities and Services

Except in the case of the lower end of the small capacity launch vehicles, alternatives to Government ranges for launch service operations do not currently exist. Consequently, the Air Force has developed a Model Range Use Agreement which sets forth the terms and conditions under which it will permit use of ranges, facilities and associated goods and services to commercial entities in support of production and/or launching of commercial expendable launch vehicles on a cost-reimbursable basis.

U.S. launch service providers have expressed concern over provisions in the Model Agreement regarding: (1) terms and conditions of the U.S. Government's ability to preempt commercial launches, (2) leaving the establishment of firm prices for range use to subsequent agreements and (3) the degree of liability placed on the commercial launch service provider, their subcontractors and customers.

Concern has been expressed by launch service providers and prospective customers alike that the provisions in the Model Agreement concerning U.S. Government preemption of commercial launches are too vague to provide reasonable launch scheduling assurances. The prospective customers state that the uncertainties concerning the possibility of preemption makes them reluctant to sign firm contracts with U.S. launch service providers.

Launch service providers have expressed frustration that the Model Agreements do not establish firm prices for using Government range facilities and services. As a result, these companies have had to use range pricing estimates for dealing with prospective customers. They have complained that they cannot maximize their efficiency or competitive position in this market without the ability to identify their total costs.

The Model Agreement makes launch service providers responsible for all property damage and third party liability, including that caused by the U.S. Government, its contractors and subcontractors, to the extent of the maximum available insurance worldwide for any specific launch. The agreement does not limit the amount of liability that commercial launch services providers, their subcontractors or customers can incur.

The U.S. commercial launch services providers have taken the position that the lack of such limits places an unreasonable and potentially unacceptable business risk on them, their subcontractors and their potential customers. They express great concern over the unlimited third party liability for themselves and the Government. Acceptance of such liability is equivalent to betting the company on every flight. It also subjects the company's subcontractors and customers to potential liability as a party to the incident, and as a result, weakens their ability to compete with foreign launch service providers, whose governments indemnify them for these elements of liability.

The Administration and the Sub-committee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives each have proposed legislation to address these concerns.

Government As Customer

The requirements of the new National Space Policy for the Government to purchase commercially available launch services and the prohibitions against Government competition with the commercial sector are intended to significantly expand the market opportunities for both large and small capacity launch service providers. This has already begun to happen in the case of large capacity ELV opportunities. As noted in the market section, all three U.S. launch service providers have been awarded substantial launch contracts by the U.S. Government, sufficient to keep production lines operating for years. This will provide a foundation on which to produce additional vehicles for meeting launch service requirements of U.S. commercial and foreign entities as well. These long-term production lines could result in greater production efficiencies, translating into lower costs and increased flexibility to compete against foreign launch service providers.

Despite these signs of progress, however, the launch companies have stated strongly that certain traditional Government procurement practices act as a barrier to their viability in the highly competitive commercial space transportation business. Specific practices cited include: specialized, unique Government performance or design requirements that differ from commercial requirements; Government preemption of commercial priorities; Government refusal to indemnify; Government insistence on loading all risks on the contractor, or demanding excessive insurance; Government insistence on scheduling control; Government design specifications, changes clauses; Government inspection procedures; Government interface requirements; Government documentation and reporting requirements; and Government solicitation and evaluation procedures/requirements, audit, accounting requirements.

As previously indicated, the commercial opportunities for provision of small capacity ELV services are also significant. The new National Space Policy requires the Government to purchase commercially available launch services to the fullest extent feasible. It also prohibits NASA from maintaining an ELV adjunct to the Shuttle. As a result, NASA, DOD and other U.S. Government Agencies with small capacity launch requirements must look to the commercial sector for these services, instead of continuing to purchase the vehicles for their own operations. Several commercial firms exist that could provide these services.

Promoting Free and Fair Trade Internationally

U.S. launch service providers maintain that foreign markets are not as freely accessible to U.S. launch companies as is the reverse. This is particularly true in the Soviet Union and China. There is real concern that allowing countries with closed economies and offering non-market based prices for space transportation services to compete openly in the international market could undermine the commercial launch industry. For example, the People's Republic has indicated that the prices for launch services on the Long March ELV will be 15 to 20 percent lower than the Ariane and U.S. commercial ELVs. It is difficult to establish the relationship between cost and price in non-market economies. However, the relationship will have to be resolved before entities are permitted to use the Long March to launch U.S.-built satellites.

Further, U.S. companies have complained of difficulties in selling small-capacity launch services overseas, saying the U.S. Government provides launch property and services to foreign governments at the U.S. Government's own favorable high volume acquisition costs, with technical data and software provided free. These practices undercut market prices and hurt U.S. commercial companies marketing similar vehicles.

The Need For A Committed Commercial Space Policy

Industry representatives have stated that one of the greatest impediments to the establishment of a U.S. commercial space transportation industry has been the failure of the U.S. Government to follow through with its stated commercial space policies. The key areas of concern identified by industry are the following: the remaining problems with the Model Range Use Agreement must be resolved; the U.S. Government must not compete with U.S. industry in the provision of launch services; the traditional U.S. Government procurement practices and laws must be reformed to permit efficient procurement of launch services on a commercial basis.

Industry representatives say failure by the Government to resolve these problems undercuts confidence in the U.S. Government commitment to space business. Consequently, companies interested in commercial space business might have difficulty raising outside capital to support their ventures or might be unwilling to commit internal resources to such projects. U.S. space companies have indicated that their willingness to invest is directly related to the effectiveness and consistency of implementation of commercial space policy.

Long-Term Prospects

U.S. launch companies say their long-term prospects are dependent upon stable U.S. Government policies conducive to commercial space activity. These companies indicate that any hint that the Government might one day re-enter the commercial launch business would undercut their ability to raise capital for private commercial ventures. They believe Government must make significant changes in its procurement practices to permit purchases of commercial launch services. They are also concerned that failure of the U.S. Government to assure free and fair trade in international launch services could eliminate the ability of U.S. commercial space transportation companies to be competitive. At the same time, these companies look to the U.S. Government to conduct research and development of new technologies to make the next generation of space vehicles more efficient. Further, they state that a continued Government role in research and development of advanced space transportation technologies is essential if U.S. commercial space transportation service providers are to remain competitive.

II. SATELLITE COMMUNICATIONS

The communications satellite industry is the most mature of all commercial space markets. Communications satellites constitute a vital part of a much broader global telecommunications network, composed of many different technologies and types of systems. From their vantage points in space, they provide a variety of services, accessible on land, sea, and in the air, some of which cannot economically be replicated by other communications technologies.

Satellites excel at providing cost-efficient point to multi-point voice, video, and data services for a wide range of government, business, entertainment, and educational applications. In less developed areas and where geographical features make the establishment of terrestrial links difficult, satellites provide perhaps the only reliable means of communication. New applications, such as global position determination services are currently unique to communications satellite technology. One of the most important applications of this technology has been the establishment of satellites and ground stations that interconnect on a global basis, allowing instantaneous communications between all areas and peoples of the world. This has led, among other things, to freer information flow, stronger international business relations, greater cultural exchange, and a safer worldwide political environment.

BACKGROUND

The current U.S. and international communications satellite environment has been shaped by advances in technology, rapidly expanding markets for communications services and the regulatory structure.

INTERNATIONAL ENVIRONMENT

The international legal and regulatory environment has been shaped principally by the agreements establishing four international organizations: the International Telecommunications Union (ITU), the International Telecommunications Satellite Organization (INTELSAT), the International Maritime Satellite Organization (INMARSAT), and the European Telecommunications Satellite Organization (EUTELSAT). The United States is a party to all of these organizations except EUTELSAT, which is comprised only of European countries.

The ITU, among other things, establishes regulations and procedures to provide countries with a framework for coordinating and registering their respective use of the radio frequency spectrum, in order to avoid causing each other harmful interference. As part of this framework, the ITU is responsible for allocating the radio frequency spectrum among the various identified radio communications services.[1]

INTELSAT and INMARSAT are global communications satellite cooperatives whose prime objectives are to provide space segment for international public telecommunications, and international maritime services, respectively. EUTELSAT is a regional satellite organization whose prime objective is to provide space segment to its European members to meet their pan-European requirements. Each of these organizations is based on two international agreements -- one signed by the member countries (Parties) and one signed by each Party or its designated representative (Signatory) responsible for day to day participation in the organization.[2] There are 114 Parties to the INTELSAT Agreement, 54 Parties to the INMARSAT Convention and 26 Parties to the EUTELSAT Agreement. Each organization has the same number of Signatories as Parties.

The Agreement between Parties in each of the satellite organizations recognizes the rights of Parties, Signatories and other entities under the jurisdiction of Parties to establish or use separate satellite systems to meet their telecommunications requirements. However, each organization requires Parties and Signatories to consult with the organization prior to establishing such systems. This is to ensure that the separate system is technically compatible with the organization's system, and to ensure that it will not cause significant economic harm to the organization. The recommendations from the consultations are non-binding, but they carry substantial political weight.[3]

For most countries, the Signatory is the governmental post, telegraph and telephone (PTT) agency or designated operating entity. Each of these organizations is jointly financed and owned by the Signatories, with ownership shares based on their proportional use of the system. The U.S. Signatory is Comsat, whose ownership share is approximately 25 percent in INTELSAT,[4] and 28 percent in INMARSAT.[5]

U.S. ENVIRONMENT

The cornerstone of U.S. telecommunications law is the Communications Act of 1934, as amended.[6] It establishes the Federal Communications Commission (FCC) as the regulatory and licensing authority for non-Federal Government use of the radio- frequency spectrum. Against this backdrop, the 1962 Communications Satellite Act (Satellite Act) provides for the establishment of a global, commercial communications satellite system (now known as INTELSAT) and provides for the establishment of a private corporation, Comsat, as the sole U.S. participant and investor in the system. The Satellite Act requires Comsat to provide non-discriminatory access to the system for all authorized users.[7] Importantly, the Satellite Act states that it is not intended to preclude the establishment of communications satellites separate from INTELSAT that are determined to be in the national interest or required to meet unique governmental needs.[8]

Three separate policies have been established to ensure that U.S. domestic and international satellite telecommunications activities are consistent with U.S. law and international agreements: (1) the U.S. Domestic Satellite Policy, which is intended to ensure a robust domestic satellite marketplace, (2) the Transborder

Policy that applies to domestic systems used to provide incidental international services to neighboring countries, and (3) the U.S. Separate Systems Policy for satellite systems intended specifically to provide international public telecommunications services separate from INTELSAT. U.S. obligations under the INTELSAT Agreement were a major consideration in the creation of each of these policies.

In the early 1970s, the FCC adopted a policy of "open entry" for qualified domestic communications satellite systems (domsats).[9] This policy, which is still in effect, is based on the concept that licensing all applicants meeting the FCC's established technical, legal and financial fitness requirements for obtaining a license will encourage the development of new technologies and services at lower costs to the public. These requirements have been tightened over the years as the number of domsats has increased and the orbit/spectrum resource has become more congested. The FCC has stated that if the number of domsat applications ever exceeds the orbital positions and spectrum available, it might have to resort to administrative selection procedures, such as comparative hearings, auctions or lotteries.[10]

Use of U.S. domestic satellites for transborder services is governed by the U.S. Transborder Policy. The Transborder Policy was established by the Executive branch and the FCC to balance the efficiencies of using U.S. domestic satellites to provide service to neighboring countries within the footprint of the satellite, with the U.S. desire to avoid causing significant economic harm to INTELSAT. The Transborder Policy, established in 1981, requires: (1) a showing by the applicant that INTELSAT could not practically or economically provide the same services as the requested domestic satellite, and (2) consultation with INTELSAT pursuant to Article XIV (d) of the INTELSAT Agreement, prior to initiation of service. The FCC's transborder decisions to date have been limited almost exclusively to the authorization of video and private line voice and data services.[11]

In 1984, the President determined that U.S. international satellite systems separate from INTELSAT (separate systems) are in the national interest.[12] This determination was made in accordance with the 1962 Satellite Act and was accompanied by the conditions that: (1) such systems may provide services only through the sale or long term lease of space segment capacity for communications not interconnected with the public-switched network, and (2) at least one foreign authority must authorize use of each separate system and participate in consultations with the United States under the INTELSAT Agreement, to ensure technical compatibility with the INTELSAT system and avoid causing it significant economic harm. In 1985, the FCC used this determination and the conditions as the basis for its decision to license qualified applicants.[13]

The Transborder Policy has always been distinguished from the U.S. Policy on separate international systems, because it only concerns U.S. domsats used to provide incidental services to nearby countries. The Separate Systems Policy, on the other hand, concerns satellites that are specifically intended to provide international services, and are considered a greater threat to INTELSAT's economic well-being. Unlike the separate systems policy, the Transborder Policy does not expressly prohibit inter-connection with the public switched network, nor does it require the sale or long term lease of transponder capacity as a precondition to use. These differences, coupled with the recognition that INTELSAT has developed into a robust and highly profitable global communications satellite system, has prompted the Administration to initiate a comprehensive review of U.S. international satellite policy. This process is underway.[14]

U.S. NATIONAL SPACE POLICY

The U.S. National Space Policy requires the U.S. Government, in meeting its space-related requirements, to purchase commercially available space goods and services to the fullest extent possible. This includes communications satellites, ground stations, and related equipment and services. The U.S. National Space Policy prohibits the U.S. Government from competing with or deterring commercial entities in the provision of commercial communications satellite services except for national security or public safety reasons. It also requires the U.S. Government to promote free and fair trade internationally in space goods and services. Finally, it requires the Government to continue research and development efforts for future advanced space communications technologies, and to provide for timely transfer of these technologies to the private sector, protecting their commercial value and without Federal subsidy.[15]

III. SATELLITE REMOTE SENSING

Satellite remote sensing of the earth is a technique for measuring the properties of the earth's land, ocean surface, and atmosphere from space. The sensors on the spacecraft collect electromagnetic radiation reflected from or emitted by the object under investigation. This collected radiation is used to determine the properties of the object. Ocean properties include sea surface temperature, wave height, current direction and speed, reflectance of substances in the water, and water depth. Atmospheric properties include temperature and cloud cover as a function of height, cloud movement and thickness, water vapor distribution, and the concentration of trace gases as a function of height. Properties of the land include vegetation type and health, mineral substances in the soil, geography, topography, water bodies, and urbanization.

BACKGROUND

The U.S. land remote sensing satellite system, now known as Landsat, began as an experimental program conducted by NASA.[1] The system was declared operational in 1983 and turned over to the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) as part of a Presidential directive transferring the program to commercial operation by the private sector.[2] This Directive was followed by the Land Remote Sensing Commercialization Act of 1984 (Landsat Act), which established the broad policy and financial requirements of the transfer.[3]

In addition to the transfer provisions, the Landsat Act authorizes the Department of Commerce, in consultation with other Federal Agencies, to license private remote sensing space systems that comply with the provisions of the Act as well as international obligations and national security concerns of the United States. These obligations and concerns include making unenhanced data available to all potential users on a nondiscriminatory basis.[4] Regulations for licensing of private remote sensing space systems have been established by the Department of Commerce.[5]

The Landsat Act also requires NASA to continue and enhance its research and development programs concerning remote sensing technologies, and to enter cooperative R&D arrangements with public and private sector research entities As a complement to NASA's activities, the Commerce Department is required to conduct a continuing program of research and development in remote sensing applications for monitoring the earth and its environment, and for the advancement of technology for such monitoring. The Departments of Agriculture and the Interior are also encouraged by the Landsat Act to conduct R&D programs in applications of remote sensing, including cooperative programs with public or private sector.[6]

Pursuant to the Landsat Act, the Department of Commerce conducted a competitive bidding process, and as a result, contracted with the Earth Observation Satellite Corporation (EOSAT) to "commercialize" the Landsat system. EOSAT is a joint venture of GM/Hughes and General Electric Corporation. According to the original contract, the U.S. Government would continue to cover the basic operational costs of the Landsat program through the expected lifetime of Landsat 4 and 5. EOSAT would market data from Landsat 1 through 5, and would design, construct and operate Landsat 6 and 7. The U.S. Government would appropriate $250 million in funding for this purpose, plus launch costs, with any additional investment coming from EOSAT's corporate funds. EOSAT would pay all operational costs of Landsat 6 and 7.[7]

The U.S. Government provided $90 million for the Landsat contract with EOSAT for FY 1985 and 1986. During the formulation of the FY 1987 budget, the Administration eliminated all additional funding for the program to comply with the budget cuts mandated by the Gramm-Rudman-Hollings Act. Because the U.S. Government reneged on its payments, EOSAT stopped work on Landsats 6 and 7 in January 1987.

During this period, the Administration and Congress attempted to develop a plan for the continuation of the Landsat commercialization program that could meet the requirements of the Gramm-Rudman-Hollings Act. In October 1987, an agreement between the Administration and Congress was reached that consisted of the following: (1) $209 million to cover funds already expended and additional work to complete Landsat 6, (2) $50 million to the Air Force to provide one Titan II launch, and (3) a study to be performed by the private sector, administered by the Department of Commerce, on options for a commercial advanced earth remote sensing satellite system. The study is to assess domestic and international markets for remote sensing data, financing options, sensor and data processing technology, and spacecraft technology and launch options.

In March 1988, NOAA and EOSAT reached agreement on the contract modifications necessary to permit restart of work on Landsat 6. At the same time the Department of Commerce signed three contracts for the study of follow-on commercial remote sensing systems.

U.S. NATIONAL SPACE POLICY

On Feb. 11, 1988, the President announced a new Directive on National Space Policy and Commercial Space Initiatives. The aspects that pertain to satellite remote sensing are described below.

The Directive states that the U.S.Government will: (1) encourage the development of commercial systems which image the Earth from space competitive with or superior to foreign-operated civil or commercial systems, (2) discuss remote sensing issues and activities with foreign governments operating or regulating the private operation of remote sensing systems, and (3) continue a research and development effort for future advanced, remote sensing technologies. Commercial applications of such technologies will not involve direct Federal subsidy.

The Directive further states that management of Federal civil operational remote sensing is the responsibility of the Department of Commerce, and requires the Department to: (1) consolidate Federal needs for civil operational remote sensing products to be met either by the private sector or the Federal Government, (2) identify needed civil operational system research and development objectives, and (3) in coordination with other Departments or Agencies, provide for the regulation of private sector operational remote sensing space systems.

Finally, the Directive emphasizes the importance placed by the Administration on the private sector study of options for commercial follow-on systems.

U.S. INDUSTRY VIABILITY ASSESSMENT

The following section represents a distillation of current industry views on factors affecting the commercial prospects or viability of this industry sector. The industry concerns presented here have been expressed during the last year to the Department of Commerce through briefings by more than 100 companies covering the entire range of commercial space activities.

The views expressed here are those of space industry representatives and do not necessarily constitute policy recommendations by the Department of Commerce. This section is intended to provide a basis for more informed discussion of these issues. Where a diversity of industry views exists, an attempt has been made to present the various industry views in a balanced manner.

International interest and competition in remote sensing is intense and increasing. By 1995, U.S. value-added companies expect to be customers of the Japanese, Indian, Canadian, and Brazilian systems in addition to the U.S., French, and Soviet remote sensing satellites they currently access. Unfortunately, it is likely that there will be a multi-year period between the demise of the Landsat 4 and 5 satellites and the launch of Landsat 6. All U.S. commercial data users and value-added companies will have to rely exclusively on foreign sources for current data during this time period; however, retrospective Landsat data will be available.

The U.S. private sector has the technological capability to provide a wide range of satellite hardware, data processing systems, and data analysis software to meet most domestic and international needs; however, many U.S. companies interested in entering the remote sensing industry have had difficulty raising the necessary capital, because of the uncertain future of the U.S. Landsat system. Some of these contend that U.S. Government funding of EOSAT chills the financial community from supporting a privately financed system. Should competition be created in the providing of raw data (development of private sector sensors and satellite systems), these companies indicated that they would seek to develop sensors appropriate for specific market niches. Others, including EOSAT, argue that U.S. Government support of the space segment is necessary to insure the continuation of the U.S. land remote sensing industry.

Despite the different opinions regarding the viability of a privately funded remote sensing space segment, there is little disagreement that U.S. companies will remain a strong force in the value-added area. This sector prefers U.S. Landsat data, but will not collapse without it, as long as data is available from other sources. U.S. data is preferred because of its multispectral capability, and because its availability reduces the chance of foreign suppliers not adhering to the twin policies of Open Skies and non-discriminatory access to data. In addition, there is unanimous agreement within the industry that the instability of the U.S. policy concerning the fate of the Landsat system is counter-productive.

The viability of the U.S. spacecraft and ground system suppliers is not tied to the remote sensing industry. Satellite system components are used on a wide variety of space systems and considerable sales opportunities exist domestically and internationally. Spacecraft component manufacturers expect a reasonable degree of market growth in the area of low earth orbit platforms, taking into account the expected demand for polar platforms for earth observation and a host of free-flying platforms for multiple functions including materials processing in space.

In terms of sensor development and construction, little demand exists in the commercial sector except for remote sensing and possibly meteorological satellite systems in the future. These are small number production items even including foreign sales. The EOSAT hardware program for Landsat 6 anticipates several types of sensors, but none that significantly advance the state of the art. The 15-meter panchromatic sensor is not an improvement on the SPOT 10-meter sensor, but it offers some advantages. The Landsat 6 TM will have spectral resolution unobtainable from any other planned device, for the next several years.

Industry sources say sensor development will move on a twin path in the next generation of systems. There will probably be relatively simple, inexpensive devices that provide moderate resolution data over a wide field of view. These devices will produce a data stream similar to TM spectral diversity, but probably will have multilinear array detectors. These instruments will be for survey measurements, possibly with a forward and backward stereo capability. The second track will probably be very high resolution, multispectral band devices for selective imaging. A 5- to 10-meter spatial resolution, 5- to 7-band (selectable from among 25 to 50) spatial resolution instrument would probably be the next logical step. Such an instrument would be followed by an imaging spectrometer. These devices will be expensive and have very large data rates. Therefore, market demand will play a very large part in the timing of their introduction. It is also likely that radar devices will be introduced early in the 1990s. Altimeters, scatterometers, and synthetic aperture radars are all under discussion and provide an outstanding complementary data base to the optical instruments.

Long Term Prospects

Sensor improvements depend on solid state detectors which can be fabricated into large scale multilinear arrays, which is really a microcircuit technology. In addition, the provision of data in more narrow spectral bands, allowing more precise mapping of the ground below, requires the development of more sensitive solid state radiation detector materials. Instead of just one dimensional arrays, the development of a two dimensional detector array would be a major step toward an imaging spectrometer, in which the earth surface could be imaged in a large number of spectral bands. New detectors in the early 1990s likely will be linear arrays, but by the turn of the century, an imaging spectrometer could be the workhorse device.

With the development of advanced devices, the data rates become almost unmanageable. As a result, some type of onboard data storage and analysis will be necessary. The French Spot system now has a 55 megabit/sec. tape recorder (Landsat does not record data). Significantly higher speed tape recorders will be necessary, and the development of high reliability systems is now in process. The development of onboard magnetic tape recorders is a market currently dominated by the U.S. and specifically, by RCA and Odetics.

Further, rather than trying to downlink all the data, some type of on-board artificial intelligence processor will be necessary. If cloud covered regions and other types of "poor" data could be removed before downlink, the data transmission problem would improve. Therefore, simple systems to detect bad data (and so note in the data stream) and artificial intelligence systems of more extensive capability are vital. These markets will be important ones for the remote sensing systems of the future.

Limited stereo capability, of the side to side type, is available on Spot. Improved stereo capability would be obtained from forward-backward, same-path images. The development of sophisticated software systems to interpret this data would provide a major improvement in remote sensed data since considerably better height information would be available.

Data distribution and storage is a major problem now, and with greater data rates in the future, will only get worse. A single TM scene (seven bands) requires four computer tapes. However, that same amount of data can be put on one CD ROM. Therefore, the development of CD storage devices will be of major importance.

Finally, the opportunity to perform active remote sensing will open up new areas of analysis. Rather that being limited to reflected energy from the sun, sources on the spacecraft could provide major additional data types. At this time the most advanced technique of this type are radar systems, such as the synthetic aperture radar (SAR). Radar and microwave sources and sensors are developed to the point where they can fit to the size, weight and power restrictions of spacecraft, and are already being developed for future spaceflight. Additionally, the development of infrared solid state lasers at low cost, primarily since they are currently used in compact disc players, provides the opportunity for active infrared remote sensing.

In the area of data analysis, major improvements are possible. Compared to the space systems, data analysis is in its infancy. The information content of the data far exceeds the present capability to make use of the data and to further analyze it. The development of microcomputer based data analysis facilities has been a major improvement. Up to several years ago, data analysis required at least minicomputer systems of over $150,000. With the improvement in the capability of micro systems, it is now possible to get into the image analysis business for under $40,000. The next major improvement in computing power will probably be the development of small parallel processor systems. Image analysis does not usually involve complicated computations, but it requires that simple calculations be done on a very large number of points. Again, this is an emerging new market which has important applications for both civilian and military remote sensing systems.

The value-added industry appears to have reasonably good prospects, with the only possible major problem coming if there is no US supplier and other nation systems will not fill their orders. Value-added companies will soon have foreign competitors, and there may be reluctance on the part of international customers to use U.S. services, but that has not been reported as a major problem at this time.

IV. SPACE-BASED INDUSTRIAL FACILITIES

Existing and planned space-based industrial facilities range from relatively simple platforms to fully equipped orbiting laboratories and industrial production facilities capable of supporting manned activities in a shirt-sleeve environment. These facilities can provide accommodations for scientific research, materials processing, satellite assembly and servicing, technology development, remote sensing, and other activities.

The range of existing or planned facilities indicates that different types of space-based activities will have varying requirements, particularly in power, volume, pressurization, on-orbit duration, and degree of sustained microgravity. For example, some types of materials processing in space will require free-flying facilities with high power, large volume, and textended periods of microgravity. Fully automated, unmanned, and man-tended facilities will be best suited for this type of activity. On the other hand, a basic research laboratory might require sustained manned presence to allow frequent monitoring and interaction with equipment and experiments.

BACKGROUND

Space-based facilities involve a diverse set of technologies, including structures, telecommunications, power, propulsion, life support systems for manned facilities, and robotics for those that are fully automated. Though these various technologies are complex, many are ready to be offered commercially. They have been employed as basic elements in all of the major international space programs.

The launch of Skylab in 1973 represented the first U.S. effort to establish a manned orbiting laboratory. Most of the required technologies for the facility already had been developed during the Mercury, Gemini, and Apollo programs of the previous 15 years and Skylab was largely the product of existing hardware left over from the Apollo program. In fact, the Skylab module, which included a spacious two-story accommodation for a three-man crew, was a converted S-IVB stage of a Saturn V moon rocket.

In the case of unmanned, fully automated facilities, the technological base is substantially greater. The U.S. has been successfully launching fully automated satellites, probes and other payloads into earth orbit and beyond since 1958.

The Soviets have concentrated on establishing space-based facilities since beginning their space program, over the years developing an array of manned and unmanned stations. Their manned space-station program has been continuously active since the 1960s. Leonid Brezhnev said "Soviet science considers the creation of orbital stations with changing crews as the highway of man into space," and in building their highway, the Soviets are developing an infrastructure that includes fully automated cargo vessels for ferrying supplies between earth and the manned stations. Since 1977, they have had people in orbit for an average of six months out of every year, and continuously since 1985.

In addition to the U.S. and the U.S.S.R., Europe, Japan, and the People's Republic of China have made major commitments to developing space-based facilities. Their objectives are not limited to national pride and scientific knowledge, but include economic returns from the development and application of space technology.

PRESIDENT'S COMMERCIAL SPACE INITIATIVE

The President's Commercial Space Initiative recognizes the economic necessity of U.S. commercial participation in space,[1] and it places particular emphasis on providing commercial opportunities for establishing space-based facilities.

The President's Initiative commits the Federal Government to act as an "anchor tenant" in a commercially developed space facility suitable for research and commercial manufacturing. Space in this facility (to be available no later than 1993) is to be used or subleased by various Federal agencies that are interested in microgravity or other types of research. The contract for these services should be announced by the end of 1988.

The Initiative also commits NASA to make its best effort to fly the SPACEHAB module, a commercially developed, owned and operated Shuttle-based research facility, on the Space Shuttle in the early 1990s.

During the next five years, the Initiative offers at no cost the Space Shuttle's expended external fuel tanks for commercial and non-profit endeavors, such as research, storage, and manufacturing in space. NASA will provide any necessary assistance or technical help on a direct cost basis, but if private-sector demand exceeds fuel-tank supply, NASA may auction the external tanks.

Finally, the Initiative requires NASA, in coordination with the Office of Management and Budget, to revise its guidelines on commercialization of the U.S. Space Station . These revisions will clarify and strengthen the Federal commitment to private sector investment in this program.

THE SPACE-BASED FACILITY MARKET

Existing and planned space facilities can be described in three basic categories: (1) unmanned, (2) man-tended, and (3) permanently manned. Most unmanned facilities are designed with on-board power systems, telecommunications, propulsion, and attitude control to support a variety of scientific and commercial space activities. Man-tended facilities provide pressurizable volume to support manned activity when connected with a manned vehicle's life support system. Permanently manned facilities provide fully pressurized habitats that allow the continuous conduct of manned space activities. Most facilities will be controlled by robotics and tele-operation from earth during unmanned periods.

All of the existing and planned U.S. facilities can be deployed by the Shuttle. With varying degrees of modification, most also can be deployed by expendable launch vehicles (ELVs). Except for capsule-type facilities designed with reentry capability, these facilities will require periodic servicing on-orbit, which might include exchanging existing research and industrial payloads for new ones, supplying raw materials for space processing, retrieving finished products and repairing the facility and equipment. Servicing for manned facilities would also include staff rotation and re-supply of consumable materials. Though current designs rely exclusively on the Space Shuttle for servicing, some of the second-generation facilities are expected to be serviceable entirely by unmanned vehicles with sophisticated robotic and tele-operation capabilities.

The three characteristics of space-based facilities which are most important for industrial research and applications are the microgravity level, the period of undisrupted microgravity exposure, and the amount of power available. The microgravity level is determined by the design and operation of the facility, with current and near-term facilities ranging from one-thousandth (10^{-3} g) of the gravitational acceleration experienced on earth ("g") to possibly one-ten-millionth (10^{-7} g). The microgravity level required or desired by researchers varies with the nature of the experiments being conducted. Having less than the required microgravity level adversely affects the speed and accuracy of experiments.

The length of time that a given microgravity level can be maintained is also important. Important areas of microgravity research, such as crystal growth, require weeks or months of undisrupted microgravity exposure for many experiments.

A fundamental constraint on materials research and processing activities in space at this time is the very limited power available for experiments. Materials research and processing can demand much higher power levels than many other commercial space applications, such as communications or remote sensing. Production rates will be very limited, and some classes of experiments will not be feasible, until facilities with more power--at a reasonable cost--become available.

U.S. COMMERCIAL SPACE-BASED FACILITIES

Several U.S. companies are actively seeking to establish privately owned and operated industrial facilities in space. These companies include SPACEHAB, Space Industries Inc., and External Tanks Corporation. Others, such as Fairchild Industries, Wyle Laboratories Inc., GM/Hughes Aircraft, Ball Aerospace, Teledyne Brown, and GE Astro Electronics have made investments to develop concepts and designs for such facilities, but have not announced plans to go forward with these ventures on a commercial basis.

SPACEHAB Inc. is developing a pressurized module to extend the amount of working and storage space on the Space Shuttle. This facility will occupy up to one-third of the Shuttle's cargo bay and connect with the crew compartment by tunnel. SPACEHAB will rely on Space Shuttle power sources, but will provide its own experiment accommodations plus environmental-control and life support systems[2]

SPACEHAB will be permitted to access on a continuous basis up to one-half of the 7 kW of Shuttle's power that is allocated to the payload bay, or 3.5 kW. Of this amount, 0.3 kW will be required to operate the SPACEHAB itself, leaving 3.2 kW for SPACEHAB payloads. In addition, SPACEHAB will be permitted to access up to 5.7 kW up to 15 minutes every three hours for specific payload requirements, such as MPS furnace operations. The availability of these power levels is based on a seven-day Shuttle mission. The microgravity environment achievable on SPACEHAB is 10^{-3} g to 10^{-5}g.[3]

SPACEHAB has a Memorandum of Understanding with NASA that recognizes the importance of extending work and storage space on the Shuttle. SPACEHAB's first flight is planned for 1991, according to NASA's March 1988 Shuttle Manifest. McDonnell Douglas Astronautics Company has been selected as prime contractor to design and build the modules.[4]

Space Industries Inc., in partnership with Westinghouse and Boeing (Space Industries Partnership), is developing a multi-purpose facility called the Industrial Space Facility (ISF), which will provide a pressurized, shirt-sleeve work environment when docked with the Space Shuttle or the Space Station. It will serve as a fully automated free-flyer for long-term unmanned operations.

The ISF will be capable of providing extra power to the Space Shuttle and extending its time on orbit while in the docked mode. Two solar arrays are designed to provide an average power of 7 kW to ISF users, with up to 10 kW available as requirements arise.

Other design characteristics include a pressurized volume of 2,500 cubic feet and the ability to support payloads weighing up to 5,500 kg (12,100 lbs) The ISF module is 35 feet long and 14.5 feet in diameter. It will also be capable of maintaining a microgravity environment of 10^{-6} g to 10^{-7}g. With these capabilities, the ISF could serve multiple functions, such as a manufacturing facility, an assembly platform, a research laboratory, a Space Station test bed, a power source or a storage facility.[5]

The ISF is designed to be launched and serviced by the Space Shuttle and to achieve full operational capability with one launch. As a fully automated free-flyer, the ISF is designed to maintain its orbit for periods up to three years without resupply, during an engineering design life of 30 years on-orbit. Design work indicates that a number of ISF modules can be joined together to increase power capabilities, volume, and efficiency.

The Space Industries Partnership has signed a Space Systems Development Agreement (SSDA) with NASA, which allows the company to delay payments to

NASA for the cost of three Shuttle flights until cash flow from commercial operations begins.

The External Tanks Corporation (ETCO) has proposed that the Space Shuttle's external fuel tank, which is dropped and lost to disintegration on each flight, be transported to low earth orbit for refurbishment and use as a space-based facility.

Measuring 27.6 feet in diameter (wider than a Boeing 747) and 154 feet in length, the external tanks have a capacity of approximately 75,000 cubic feet. ETCO proposes to convert the tanks into pressurized and non-pressurized chambers for use as storage depots, scientific workshops, space farming platforms, manufacturing facilities, and manned habitats. NASA feasibility studies indicate it can be done.[6]

A number of U.S. companies have designed and developed unmanned space platforms for commercial use. These platforms would have power, communications capability, and attitude control to support various space-based activities, such as materials processing or scientific experiments, and could accommodate modular attachments for earth sensing, telecommunications, and other activities. They could be deployed by the Shuttle or by expendable launch vehicle (with modification required in some cases).

The most developed of these platforms is one designed by Fairchild Space Company, called "LEASECRAFT".[7] The design is for a modular platform, based on the same modular concept Fairchild used successfully in the Landsat and Solar Maximum Mission (SMM) satellites. The modular design of the SMM satellite enabled the successful repair of the satellite on orbit in 1984.

LEASECRAFT was designed to carry primary payloads of up to 14,500 kg (31,900 lbs) and secondary payloads of up to 1,000 kg (2,200 lbs). It could provide an average power of 5kW for payload requirements, with peak power of 7.5 kW or more for limited durations. Fairchild's LEASECRAFT is designed to achieve a microgravity environment of 10^{-6}g to 10^{-7}g. The company has a Joint Endeavor Agreement until 1995 with NASA for launch and servicing LEASECRAFT, but it has delayed development of the project until the Government contracts with Fairchild for use of the platform or the company has commercial customers.[8]

Another type of unmanned facility with commercial potential is the reentry capsule developed and manufactured by General Electric. These capsules were originally used by the U.S. Government to return film packages from surveillance satellites. The capsule is launched by an ELV and provides a protective environment for the payload on-orbit and during reentry. During the orbital phase, the capsule can achieve a microgravity environment of 10^{-5}g to 10^{-6}g. The capsule has a de-orbiting motor, a ram-air gliding parachute, and a claimed targeting accuracy of 15 meters. Commercial applications could include photography and remote sensing, materials processing, and the return of samples from longer duration space-based facilities.[9]

U.S. INTERNATIONAL SPACE STATION

The United States, with participation by the member countries of the European Space Agency, Japan, and Canada, is planning to establish a permanently manned Space Station in the 1997 to 2000 timeframe. The manned base of the Space Station will consist of a truss structure with utilities, communications system, and four pressurized modules attached for permanent habitation and laboratory work. The power source to the Space Station will be solar photovoltaic power modules, which will provide a total of 75 kW. This total power will be allocated on a priority basis to essential Space Station operations, with the excess available for meeting user requirements. The Space Station will be capable of achieving a microgravity environment of 10^{-3}g to 10^{-5}g.

The United States will provide two of the pressurized modules -- the Habitation Module and a multipurpose Laboratory Module. The European Space Agency (ESA) will provide the Attached Pressurized Module. Japan will provide the Japanese Experiment Module. Canada will provide the Mobile Service Center and the Dextrous Manipulator. The U.S. will also provide a logistics module, a fixed servicing facility and the utilities for the core base. There will also be co-orbiting and polar platforms. The United States and ESA each will provide polar platforms. ESA, will also provide a co-orbiting Man-Tended Free Flyer facility. The facilities to be provided by Canada, ESA and Japan are more fully described in the following section on "Foreign Providers."

Four U.S. companies were selected in December 1987, to negotiate contracts with NASA for prime contractor responsibilities concerning the Space Station. Rocketdyne won the competition for building the power generation and distribution system, including the solar arrays. McDonnell Douglas won the competition for building the metal truss that will form the skeletal system of the station. They will also be responsible for the navigation, communications, airlock and propulsion systems. Boeing won the competition for building two modules for crew quarters and a laboratory, and Boeing is also responsible [illegible] the environment and life support systems. General Electric won the contract for constructing a free-flying, multi-purpose platform, and associated robotics, communications, and power system.[10]

FOREIGN SPACE-BASED FACILITIES

European Space Agency

The European Space Agency (ESA) has already developed several space-based facilities for scientific and industrial activities, and it is planning others. These include the Spacelab, the European Retrievable Carrier (EURECA), the Man-Tended Free-Flier (MTFF), the Columbus module, and polar platforms.

The Spacelab module, developed in close cooperation with NASA, is a versatile research facility. Carried in the payload bay of the Space Shuttle, it consists of pressurized modules, to provide a shirtsleeve environment for conducting complex experiments requiring manned interaction, and unpressurized pallets. These modules and pallets can be flown either together or separately on the Shuttle. Spacelab is dependant on Shuttle power, of which a total of 7 kW is allocated to the payload bay. Spacelab requires approximately 3.5 kW for its own operation, leaving a total of 3.5 kW available for its payloads. These power levels are based on a seven-day Shuttle mission. The microgravity environment achievable on Spacelab is 10^{-3}g to 10^{-5}g. Spacelab was designed and built at a cost of approximately $1 billion, with primary funding for the project provided by West Germany. Spacelab has already flown four times on the Shuttle.[11]

EURECA was developed in response to the growing demand from European researchers for the use of space-based facilities. It is an unmanned platform with its own power, communications and propulsion systems, designed to carry experiments for microgravity research and other purposes. The platform, which is based on a double Space Pallet Satellite (SPAS) body, can support payloads weighing up to 1,000 kg and can supply up to 1.0 kW of power on a continuous basis. It is designed to provide a microgravity environment of 10^{-5}g to 10^{-7}g. EURECA is to be deployed and retrieved by the Shuttle, with the capability to remain on-orbit from six to eight months. It is not, however, designed to be serviced on-orbit. EURECA was ready for launch in 1987, but due to delays associated with the Challenger accident, has been rescheduled for launch in 1990.[12]

The Columbus module, MTFF, and polar platform constitute ESA's participation the international Space Station project. The Columbus module, which will be based on the Spacelab design, will be a pressurized laboratory with volume equivalent to that of four Spacelab segments. The Columbus module will be permanently attached to the manned base, with complete basic functional outfitting. It will include provisions for storage of ESA spares, secondary storage of crew provisions, and storage for safe haven capability. The module will be used for fluid physics, life sciences, and materials sciences. It will be capable of housing up to 10,000 kg of payload. Power available to support payload activities will be dependant on the capability of the utilities package supporting all elements of the core Space Station and the manner in which the available power is allocated. The Columbus module will be launched by the Space Shuttle.[13]

The MTFF will be a pressurized, free-flying facility designed to carry microgravity research payloads that require long duration in space. Like the Columbus module, it will be based on the design of the European Spacelab. It will have a volume capability equivalent to two Spacelab segments, and will be designed to accommodate payloads up to 5,000 kg on orbit. Up to 5 kW of power will be available for payload activities. The MTFF is designed to achieve microgravity levels of 10^{-5}g to 10^{-7}g. Servicing will be performed at six month intervals by the Shuttle, and later by Hermes or at the Space Station. The facility will have its own propulsion unit to perform on-orbit manouvers. It will be launched by a single Ariane-5 ELV, with the first launch planned for 1996.[14]

The polar platform will be able to carry up to 2500 kg (5,500 lbs) of payload, with power capabilities for payload activities up to 3.1 kW. It will be capable of attaining a microgravity environment of 10^{-5}g. Current plans are to launch this platform by Ariane-5 in 1995, with nominal servicing four years later by Hermes.[15]

ESA member countries have concluded that space-based infrastructure is vital to their long-range interests with or without the development of the international Space Station and cooperation with the United States. This is demonstrated by their work independent of the Space Station preparations, and is codified by the Rome Resolution, which calls for European autonomy in manned space activities.[16]

Federal Republic of Germany

The Federal Republic of Germany (West Germany) in addition to its ESA-related projects, has developed a free-flying spacecraft called the Space Pallet Satellite (SPAS). SPAS is based on the same design concept as the pallets for the Spacelab, except that it has the additional capability to be deployed and retrieved by the Space Shuttle, and to remain in orbit for up to 10 days. It will provide a microgravity environment of 10^{-5}g to 10^{-7}g. With minor modifications, SPAS could be fitted with additional hardware and fuel to allow extended flights of several months. SPAS has flown two times on the Shuttle, and in each case it was deployed and retrieved on the same mission. It is currently available for commercial use. The prime contractor for the SPAS was MBB/ERNO.[17]

West Germany is currently considering the development of another space-based facility, called the Space Courier project. The Space Courier would be an unmanned, recoverable capsule designed primarily for microgravity research and experimentation. It would be launched by an ELV and capable of carrying payloads of 660 to 1,100 lbs. It could enter operation as early as 1991.

Japan

The Japanese have announced plans for an ambitious series of space-based facilities. One of these, the Space Flyer Unit (SFU), is being developed jointly by the Institute of Space and Astronautical Sciences, the Ministry of International Trade and Industry, and the National Space Development Agency of Japan. The SFU will be a platform 3.6 meters in diameter with six modules for use as a test-bed for basic science and applied technology, as well as materials processing experiments. Each module will have a payload capacity of 200 kg (440 lbs) Power available to experiments will be approximately 1 kW. The SFU will provide a microgravity field of 10^{-4}g to 10^{-6}g. It is intended to be launched on the Japanese H-II vehicle, and serviced by the Space Shuttle at six month intervals. The first launch is scheduled for 1993.[18]

Japan is developing an experiment module as its contribution to the U.S. international Space Station. The Japanese Experiment Module (JEM) will consist of a pressurized module, at least two Experiment Logistics Modules and an exposed facility, permanently attached to the manned base. The pressurized module will be a multi-purpose laboratory for conducting experiments in materials processing, life sciences, etc. The experiment logistics module will be a storage container for supplies and experiments. The exposed facility will be a work station for scientific observation, communications, science, and other experiments. The JEM will have a remote manipulator arm and an exposed work deck. Its dimensions will be four meters in diameter and 10 meters in length. Its engineering design lifetime is 30 years.[19]

People's Republic of China

The People's Republic of China has been launching reentry capsules since 1975 and are now marketing these spacecraft for scientific and commercial uses. These capsules can remain in orbit up to 15 days before returning to earth for recovery. They can carry experiment packages weighing up to 200 kg (440 lbs) into low earth orbit, using the Chinese Long March II as the launch vehicle. The returnable capsules are placed into an orbit of 175 km to 400 km (108 miles to 248 miles) at an inclination of 57-70 degrees. The microgravity level on-orbit ranges from 10^{-4}g to 10^{-5}g. The People's Republic has already used the reentry capsules to fly several international payloads, including a microgravity experiment package from the French company Matra. They have established a policy exempting experimental payloads from customs inspection on entering and leaving the country. In addition to reentry capsules, the People's Republic has announced plans to construct and launch a 22 ton Space Station by 1998.[20]

Soviet Union

The Soviets have maintained an ambitious space-based program since 1971. Since then, Soviet space stations have advanced significantly in sophistication of hardware design and the research performed onboard. Cosmonauts now live and work in space for more than 11 months at a time. The current station, called MIR, has been used for research and development in all major disciplines, including life sciences, microgravity research, materials processing and remote sensing. Although technical information on the MIR is limited, reports indicate that it is capable of providing up to 8 kw for user requirements, such as microgravity experiments.[21] The MIR can achieve a microgravity environment of 10^{-3}g to 10^{-5}g. Over the past several years, the Soviets have increasingly allowed use of their space-based facilities by Western countries. The French, in particular, have begun taking advantage of this opportunity. Most recently, a U.S. company, Payload Systems, Inc. was granted an export license permitting it to fly a science experiment involving protein crystallization on the MIR.

The Soviets are also marketing a returnable experiment capsule know as "Cosmos." This capsule reportedly provides basically the same dimensions, microgravity capabilities and operational capabilities as the Chinese capsule described above.

United Kingdom

The British company NIS Space Ltd. is marketing reentry capsules for commercial use. These capsules were developed by General Electric Company, U.S.A. for use by the U.S. Government. NIS Space Ltd. has obtained licenses from General Electric for this purpose.[22]

Comparison Of Space-Based Facility Characteristics

Facility	Microgravity Level	Microgravity Test Time	Max. Continuous Power To Payload
SPACEHAB	10-3 10-5	7 Days	3.2 kW
Industrial Space Facility	10-6 10-7	Months	7.0 kW
LEASECRAFT	10-6 10-7	Months	7.0 kW
GE Returnable Capsule	10-5 10-6	40 Days	Data Not Available
Space Station	10-3 10-5	Months	Distribution of 75 kW among all facilities
Spacelab	10-3 10-5	7 Days	3.5 kW
EURECA	10-5 10-7	Months	1.0 kW
MTFF	10-5 10-7	Months	5.0 kW
ESA Polar Platform	10-4 10-5	Months	3.1 kW
Japanese Space Flyer Unit	10-5 10-7	Months	1.0 kW
PRC Returnable Capsule	10-4 10-5	5-15 Days	Data Not Available
Soviet MIR Space Station	10-3 10-5	Months	8.0 kW
Soviet Cosmos Returnable Capsule	10-5 10-6	5-15 Days	Data Not Available

DEMAND FOR SPACE-BASED FACILITIES

Demand for the use of space-based industrial facilities can be divided into three categories: (1) U.S. Government, (2) U.S. Commercial, and (3) Foreign. Prospective users in all three categories agree that space provides a unique environment conducive to critical research and a wide range of potential applications. Uses of space-based facilities that have been identified by potential customers include various types of microgravity research, manufacturing and materials processing, assembling and servicing space hardware, space technology test-bed development, power generation, storage, and remote sensing.

The marketing efforts of the commercial orbital facilities sector indicate that the demand is sufficient to support reliable, low-cost facilities. The various existing or planned facilities offer a wide range of characteristics and capabilities. Therefore, the choice of facility is not based solely on cost.

U.S. Government Demand

The U.S. Government is expected to be a major customer for space-based facilities on which to conduct research in civil and national security areas.[23] With respect to civil space activities, NASA has conducted several surveys to determine its needs for space-based facilities. For instance, in response to a Congressional request for a report of potential requirements for the Industrial Space Facility (ISF), NASA listed over 30 currently planned experiments in life sciences, materials and advanced technologies that could be flown on the ISF. It also noted that the ISF could be used for developing new flight laboratory hardware and for conducting an unspecified number of experiments to establish a technology base in preparation for the use of the Space Station.[24] Upon a subsequent review, it reported that there were in fact vast requirements that could be satisfied by the use of ISF and SPACEHAB in preparation for use of the Space Station.[25]

Other studies have identified requirements for the ISF that appear to be in addition to those identified most recently for Congress. For example, six of the NASA funded Centers for Commercial Development of Space (CCDS) estimate a combined need for at least one third of an ISF type facility over a five-year period. This estimate is based solely on currently identified experiments. The Centers have stated that experience gained by using an ISF could greatly increase their demand for additional space on the facility or the Space Station.[26] Additional reports conducted recently for NASA indicate that these requirements could be significantly larger.[27]

Other Government agencies have expressed interest in conducting experiments aboard an ISF-type facility. Specifically, the National Bureau of Standards, the National Oceanic and Atmospheric Administration, the Department of Energy, the National Science Foundation, the National Institutes of Health, and the Department of Defense (U.S. Air Force and the Strategic Defense Initiative Organization) collectively have identified more than 50 experiments that they would conduct in such facilities, based on their existing or planned research programs. As with the NASA studies, these entities anticipate that requirements will increase significantly with experience in using space-based facilities.[28]

U.S. Commercial Demand

Interest has been expressed by businesses involved with aerospace, chemicals, pharmaceuticals, electronics, metals and alloys, engineering, and many other activities in using ISF-type facilities. These companies contemplate the use of such facilities not only for researching and developing new technologies for space-based applications, but also as a research test-bed for perfecting techniques with ground-based applications.[29] The recent application by Payload Systems, Inc. for an export license to conduct experiments on the Soviet MIR Space Station is a concrete example of the growing demand for commercial space-based facilities.[30]

Similarly, SPACEHAB, Inc. reports that it has received expressions of interest among U.S. Government, commercial and foreign entities for requirements sufficient to fill 10 to 20 SPACEHAB modules.[31] In addition, there is strong interest among U.S. companies in the use of inexpensive reentry capsules, such as those offered by General Electric, the Chinese or the Soviets for microgravity experimentation.[32]

There are more than 600 secondary payloads on the Shuttle manifest, approximately 50 percent of which are MPS experiments. Approximately 70 percent of the MPS experiments are sponsored by NASA's Office of Commercial Programs. While the Space Shuttle represents a near-term opportunity for conducting short-term materials research in space, it is limited in the amount of on-board space it has available for experimentation, in the amount of power it can supply to experiments, and the length of time it can remain on-orbit. Furthermore, the uncertain flight rate for the Shuttle when it returns to service, competing high priority elements for its use and the lead-time required for Shuttle integration limits its attractiveness for ongoing microgravity research programs. Facilities that can expand the Shuttle's available space and power capability, and alternative facilities for longer duration on-orbit, such as the ISF, are expected to attract significant new demand from the commercial and academic communities.[33]

Foreign Demand

The Europeans have demonstrated significant interest for space-based industrial facilities simply by the amount and breadth of resources dedicated to the development of space-based facilities. Their successful experience in microgravity research has led to increased demand for future endeavors. For example, the success of the materials processing, biological, and medical experiments on the Shuttle Spacelab D1 mission has led to a flood of proposals for access to the D2 mission scheduled for 1990. The FRG has paid for the entire mission. One third of the available space on Spacelab D2 has been allocated to European industry through INTOSPACE, a German consortium led by MBB/ERNO.[34]

Many of the ESA member nations have established a multi-phased microgravity research program intended to take an incremental approach to full-fledged microgravity activities. This program has as its foundation several sounding rocket and ground-based research programs, including the West German TEXUS program, the Italian TOPAZ program and the Swedish sounding rocket program. These are seen as stepping stones to space-based activities. Similarly, the Europeans plan to use the EURECA and other free-flyer modules as follow-on to their Spacelab experiments, since free-flyers can provide up to six months of undisturbed microgravity time as compared to only a week on Spacelab, with crew movements causing disturbances during this time.[35]

The Japanese are also participants in this incremental approach, having taken an active part in the West German TEXUS program. They have also purchased space through INTOSPACE on Spacelab D2, and have invested tens of millions of dollars preparing for their dedicated Spacelab J1 mission in 1991. This mission, which has significant industrial participation, will concentrate on materials processing and secondarily on life sciences.[36]

Foreign companies also have been attracted to the potential uses of reentry capsules. Substantial interest has been expressed in this regard from the U.K., France, West Germany, Sweden, Italy and Belgium. At least 10 companies from these countries have signed MOUs with the Chinese for use of their reentry capsules for various types of experimentation.[37] The Soviets too are marketing their reentry capsules for microgravity experimentation. Thus far, they have signed a contract to launch three microgravity payloads on recoverable capsules for the West German firm Kayser-Threde GmbH.[38]

U.S. INDUSTRY VIABILITY ASSESSMENT

The following section represents a distillation of current industry views on factors affecting the commercial prospects or viability of this industry sector. The industry concerns presented here have been expressed during the last year to the Department of Commerce through briefings by more than 100 companies covering the entire range of commercial space activities.

The views expressed here are those of space industry representatives and do not necessarily constitute policy recommendations by the Department of Commerce. This section is intended to provide a basis for more informed discussion of these issues. Where a diversity of industry views exists, an attempt has been made to present the various industry views in a balanced manner.

Space-based industrial facilities have proved to be technologically feasible and commercially valuable. All of the proposed U.S. commercial space facilities share the goal of providing users with basic "no-frills" work areas or platforms which employ mature, reliable technology to reduce the costs of working in space.

The need for a variety of space-based industrial facilities is clear. The current and future Government-operated facilities, such as the Space Shuttle and international Space Station, are inadequate to meet most commercial requirements other than basic research. Both will be limited in availability to commercial users due to competing civil and national security demands. They are also unsuitable for certain uses such as long-term vibration-free microgravity work since they are both designed to be permanently manned, and to carry on simultaneous, multi-purpose functions to satisfy a wide range of user requirements. The Shuttle does not have sufficient power or ability to remain on-orbit long enough for many activities with commercial potential. The Space Station, on the other hand, while having sufficient power and ability to remain permanently in orbit, will not be operational for nearly a decade. Consequently, the Space Station offers very little near-term incentive to commercial entities and the financial community to invest private capital in research and development in preparation for Space Station use.

To date, development of privately owned space-based facilities has been inhibited by uncertain access to space, high capital costs with uncertain payback periods, inadequate insurance at reasonable prices, institutional barriers, inconsistent Government policies, and foreign government-backed competition.

Access To Space

With the exception of the re-entry capsule type facilities, all of the space-based facilities are designed to rely almost exclusively on the Shuttle for on-orbit servicing and return of payloads to earth. Most of these facilities are designed to be launched by expendable launch vehicles. However, companies involved with these projects have recognized the need for unmanned servicing capabilities in view of the uncertainties and negative potential business impact resulting from total dependence on the Shuttle. These companies estimate that space-qualified systems for such fully automated operations could be developed in five to ten years.

High Capital Costs And Long Payback Periods

Space-based industrial facilities are highly capital intensive, and are considered high risk by normal business standards. Companies proposing such ventures find it difficult to compete for capital with ground-based alternatives that offer quicker and more assured return on investment.

Insurance And Risk Of Loss

Because of the seemingly disproportionate number of launch failures and satellite losses during the past four years, the available capacity of the insurance industry to cover commercial space launches has declined substantially and rates have increased significantly. As of January 1988, the total worldwide insurance capacity available for space launches was estimated to be less than $200 million. Some of the planned space-based facilities will need insurance for many times this amount. Underwriters have been unwilling to commit to insurance coverage prior to 90 days before launch. The uncertainty of whether insurance will be available at a reasonable price is a critical factor in obtaining financing for the project.

The presence of risk beyond the company's control, such as timely launch, successful flight of the Space Shuttle, and timely servicing of the facility on orbit add to the difficulty of obtaining insurance coverage at reasonable rates. The Government has been unwilling to assume this risk for commercial facilities.

Legal, Institutional And Policy Barriers

The U.S. Government is envisioned as an "anchor tenant" on several of the space-based facilities proposed by U.S. companies. The Government's requirements establish demand for use of a substantial portion of the facility. The remainder of the facility can be marketed to commercial and foreign users. Despite the benefits of having the Government as a customer, problems exist in the manner and extent to which the Government can or will abide by accepted commercial contracting practices. The Government's commitment to fund a multi-year project, such as leasing a portion of the volume in a space-based facility, may be limited to appropriations on an annual basis. Its acceptance of termination liability may be similarly limited. These limitations act as major impediments to commercial investment in space.

Foreign Government-Backed Competition

U.S. companies have long stated that they cannot compete where foreign governments provide commercial users with free or reduced cost access to Government-owned and operated facilities.

Long-Term Prospects

Orbital facilities are a necessary component of the commercial sector's and Government's utilization of space. The prior national policy of sole reliance on the Shuttle resulted in dependence on that vehicle for most of the existing designs. Due to the initial success of the Shuttle program, the expectation was that space-based facilities would be permanently manned or at least man-tended. The result is that the current designs lack the necessary robotic capabilities to eliminate Shuttle dependency and allow ELV launch and remote operation.

Some commercial orbital facilities could become available by the early 1990s if government disincentives, such as liability burdens, procurement procedures and the lack of firm scheduling on the Shuttle manifest, are removed. According to industry representatives, removing the Government as a competitor and redefining its role into one of consumer would provide a substantial customer base on which the private sector could build its market more rapidly.

As the legal and policy environments become more conducive to commercial space activities, private sector investment in space activities will increase. With increased investment will come increased emphasis on further development of space-based industrial facilities that, through the use of robotics and tele-operation from earth, can be launched, operated, and serviced without the Space Shuttle and without manned presence. This development might take place within five to ten years.

V. MATERIALS RESEARCH AND PROCESSING IN SPACE

The potential uses of the space environment are just beginning to be explored. Its two fundamental characteristics, sustained microgravity and high vacuum, have become recognized as significant areas for scientific and industrial research.

Microgravity, the characteristic that has received most attention thus far, is a state in which the force of gravity experienced is significantly less than that on the surface of the Earth.[1] *Process variables behave differently in microgravity. Buoyancy driven forces such as sedimentation and convection can be virtually eliminated. Weak surface forces, otherwise suppressed by the forces of gravity, are exaggerated. The prospect of an environment in which these variables can be better controlled has attracted the interest of researchers in such fields as biotechnology, electronics, glass and ceramics, metals and alloys, and polymers.*

Almost all of the microgravity research conducted has been in the area of materials research and processing in space (MRPS). Research in this area has already led to significant advances in materials science, to improved ground-based production methods, and to other industrial applications. Continued MRPS research could lead to commercially viable products, now unknown, that are uniquely suited to space-based production. It might be possible to produce materials in earth orbit that cannot physically or cost effectively be produced on earth. The pool of knowledge derived from MRPS research is just beginning to accumulate. As a result, it is difficult to predict with any accuracy the future commercial applications that might be developed. However, recent studies on MRPS note by analogy to ground-based research that "predictions on the impact of high vacuum, high temperatures, and pressures on all materials technologies have invariably been severely underestimated."[2]

BACKGROUND

MRPS originated in the early years of the U.S. and Soviet space programs. In the U.S., engineers were concerned about the effect of the space environment on such things as rocket propellants and the flow of metals if structures were welded together in space. Drop towers and aircraft flying parabolic trajectories were used to allow scientists very brief periods in which to observe the mechanics of microgravity. The Soviets and the U.S. began conducting biological experiments in microgravity in the mid 1960s. The Soviets started with their Vostok spacecraft. The U.S. began with its Biosatellite and expanded its program on the later Apollo flights, the joint Apollo-Soyuz mission, and Skylab.[3]

Between the end of the Apollo program and the operation of the Space Shuttle, NASA began using sounding rockets, aircraft with parabolic flight paths, high altitude balloons, and drop towers to conduct ground-based microgravity research in preparation for the use of Spacelab and longer duration space-based facilities.

In the late 1970s, the pace of NASA's microgravity research program slowed significantly, while Europe (particularly France and West Germany), Japan, and the U.S.S.R. increased their efforts.

Currently, all major space capable nations are concentrating on the development of space-based facilities to further advance their microgravity research and applications. A variety of space-based facilities, both manned and unmanned, will be deployed during the 1990s. The President's Commercial Space Initiative recognizes the need for these facilities and the need for a more coordinated microgravity research and development program in the United States.

PRESIDENT'S COMMERCIAL SPACE INITIATIVE

The President's Commercial Space Initiative announced the establishment of a National Microgravity Research Board to assure and coordinate a broader range of opportunities for research in microgravity conditions. NASA will chair this Board, with representatives from the Departments of Commerce, Transportation, Energy, and Defense, as well as the National Institute of Health and the National Science Foundation. The Board will consult with the academic and commercial sectors. The Board will be responsible for: (1) stimulating research in microgravity environments and its applications to commercial uses; (2) developing policy recommendations on matters relating to microgravity research, including types of research, government/industry/academic cooperation, and access to space, including a potential launch voucher program; and (3) coordinating the microgravity programs of Federal Agencies by reviewing plans for microgravity research, recommending priorities for use of Federally owned or leased space in microgravity facilities.

MRPS APPLICATIONS

Industrial applications of MRPS considered to date include the following production techniques:

Materials Separation: The sustained microgravity environment of space permits the use of separation techniques such as electrophoresis, isoelectric focusing, and suspension cell culturing to produce pharmaceutical products from organic compounds and living cells in solution, with greater efficiency and higher purity than on earth.

Crystal Growth: Sustained microgravity can be used to produce larger and/or higher-quality crystals than on earth, because they are free from convection created imperfections and from contaminants introduced from processing containers. Space-grown organic crystals can be used to accelerate the design of new drugs, and for protein engineering and synthetic vaccine development. Similarly, inorganic crystals grown in space can result in faster, more reliable semiconductors, solar cells, infrared detectors, solid state lasers, other currently concieved electronic devices, and completely new electronic devices.

Containerless Processing. The microgravity environment allows for containerless processing of materials, eliminating problems caused by contamination and nucleation due to contact with the surface of the container. This process can be used for the production of special glasses and optical fibers. It is potentially useful in high-energy laser applications, fusion research, and ceramics (including superconducting ceramics).

Composite Materials Formation. Sustained microgravity can be used for casting of materials of different densities that would ordinarily separate under normal gravity. In microgravity, mixtures remain suspended during melting and solidification. This process opens new possibilities for the development of higher density metals able to withstand greater heat and stress, higher strength alloys, foam metals, eutectics, and other approaches to superconductive materials.

COMMERCIAL AND FOREIGN ACTIVITY

Commercial activities related to MRPS can be divided into three general areas: (1) space-based activities, (2) ground-based activities, and (3) support services. Space-based activities consist of MRPS experimentation and the development of MRPS hardware. Ground-based testing is an essential prerequisite for these activities, owing to the high cost of space research and development. Support services and facilities consist of the vehicles for transportation to and from space, the on-orbit facilities in which the MRPS activities are conducted, and the vehicles and facilities for conducting ground-based and near-earth testing.

SPACE-BASED ACTIVITIES

U.S. COMMERCIAL ACTIVITY

A wide range of U.S. companies have demonstrated interest in MRPS activities. Aerospace companies interested in MRPS research include McDonnell Douglas, Boeing, Grumman, Rockwell Corporation, and Wyle Laboratories, Inc. Large non-aerospace corporations that have shown interest include 3M, Alcoa, Union Carbide, EG&G, Corning Glass, Bethleham Steel, General Motors, Specialty Metals Corp., Johnson Matthey Inc. and John Deere. Entrepreneurial companies involved in MRPS include Instrumentation Technology Associates, Microgravity Research Associates, Payload Systems Inc., and International Space Corporation.

Prior to the Challenger accident, some of the companies listed above were in the process of developing particular MRPS technologies for commercial production. The following examples are illustrative of the range of private sector MRPS activity that has been pursued to date.

McDonnell Douglas Astronautics Co. has developed an experimental continuous flow electrophoresis system for processing biological materials in space, that demonstrated 500 times the production rate and five times the purity obtainable in conventional ground-based devices. Although the company placed its experiments on hold after the Challenger accident, the project was to lead to full scale, space-based commercial production of rare drugs, hormones, and enzymes.[4]

Lehigh University, in conjunction with NASA, developed monodispersed polystyrene latex spheres, grown in space to the size of 18 microns with five times the uniformity of ground-based samples. Spheres as large as 30 microns with less than 2 percent deviation from perfect rounding have been produced. These near-perfect spheres are used as microscopic measuring devices for extremely precise calibrations of laboratory instruments as well as other industrial applications. The spheres were produced in limited quantities on the Space Shuttle, and are marketed by the National Bureau of Standards as a standard reference material.[5]

Several firms have undertaken efforts to develop processes for commercial production of advanced semiconductor materials in space, including gallium arsenide, cadmium telluride and indium phosphide. For example, Grumman Aerospace Corp. has joined with the Ethyl Corporation's Morgan Semiconductor Division in a $14 to 18 million MRPS program, and has fabricated two prototype furnaces for this purpose.[6] International Space Corporation has also developed crystal growing furnaces for space-based commercial production.[7] Microgravity Research Associates has supported over three years of laboratory work at Massachussetts Institute of Technology to develop an approach to growing very high quality crystals in solution, instead of using a furnace, on earth and in space.[8]

In the area of metals and alloys, Grumman Aerospace Corp. has already demonstrated the benefits of space-based research for ground-based applications. Grumman's microgravity processing of bismuth-manganese (Bi-Mn) was structurally and magnetically superior to Bi-Mn generated by the same process on the ground. The origins of the differences were pursued in six microgravity sounding rocket tests, and once discovered, incorporated into the ground processing techniques. The result, according to Grumman, was an increase in performance to theoretical levels, 70 percent greater than the original ground samples.[9]

Grumman has also demonstrated the unique effects microgravity has in damping buoyancy-driven convection during crystal growth of a magnetic composite. The objective of diffusion controlled growth was achieved. According to Grumman, this process does not appear possible on earth. As a result, it has concluded that that the microgravity process is a candidate for commercial exploitation.[10]

Instrumentation Technology Associates has developed several types of standardized MRPS hardware for sale or lease to companies interested in conducting microgravity experiments. These include a materials dispersion apparatus, which is designed to mix chemical solutions in microgravity and mass produce protein crystals, a cultural dispersion apparatus for growing cell cultures, as well as microgravity experiment modules for use on sounding rockets, the Space Shuttle and other space-based facilities.[11]

The 3M Company has committed itself to a long-term microgravity research program. It's efforts are focused more on gaining expertise and knowledge in this new field than on immediate commercial success. This approach appears to have already yielded benefits, as the company has applied for five patents to date as a result of its MRPS activities.[12]

A number of companies, including Ford Aerospace Corporation, International Business Machines (IBM), McDonnell Douglas, 3M, and others, have established a Space Commercialization Consortium (SCC) for conducting MRPS research and development activities. The consortium was formed as a privately funded R&D partnership, with emphasis on development.

Many of the activities described above have been conducted in conjunction with NASA through its Joint Endeavor Agreement (JEA) Program, which is an arrangement between NASA and a private party wherein each contributes to a project of mutual benefit. JEAs are negotiated on a case-by-case basis, and each may vary in size, complexity and respective responsibilities. The JEA approach was developed to promote commercial space activities by bridging the gap betweeen government funded demonstrations and commercial activities. Most JEAs negotiated to date have involved NASA's provision of Shuttle flights in exchange for the company's provision of experiment hardware and technical information. Rights to inventions and know-how that result from JEAs are a matter of negotiation.[13]

Companies with JEAs for MRPS activities include: McDonnell Douglas, for seven STS flights to test an electrophoresis unit it developed; 3M Company, with an agreement signed in 1987 for 62 Shuttle flights for microgravity experiments over a 10 year period; Grumman, for one Shuttle flight to test a company-developed MRPS furnace; Microgravity Research Associates, for seven Shuttle flights to conduct experiments using Liquid Phase Electroepitaxy to produce binary, ternary, and quaternary crystal compounds for electronic compounds; International Space Corporation, for six to eight Shuttle flights to test its MRPS furnaces designed for the pilot production of cadmium telluride, gallium arsenide and indium phosphide; and Instrumentation Technology Associates, for two Shuttle flights of its Standardized Equipment Module (ISEM), which provides a pressure vessel, power, data and heat rejection for MRPS users of the NASA Hitchhiker carrier.[14]

Another NASA initiative that is significant to U.S. industry's microgravity research efforts has been the creation of Centers for the Commercial Development of Space (CCDS). The CCDSs are non-profit research institutions, comprised of industry, universities and non-NASA Government Agencies whose purpose is to generate and disseminate research data on areas identified as having potential for future commercial development in space. NASA provides seed money to help establish and maintain the CCDSs for an initial period, after which the industry and university participants are expected to provide the necessary support. NASA also offers the CCDSs scientific and technical expertise, opportunities for cooperative activities and other forms of continuing activity. Industry members of the CCDSs can take their research out of the Center at any time, should they desire to pursue it privately, and take the results to market. The proprietary rights accrue from the time they take the results from the Centers. Prior results are placed in the public domain.

Thus far, 16 Centers have been established, six of which whose focus is on MRPS research. These are:

Center for Advanced Materials, Batelle Columbus Laboratories, Columbus, Ohio,

Center for Development of Commercial Crystal Growth in Space, Center for Advanced Materials Processing, Clarkson University, Potsdam, New York,

Center for Macromolecular Crystallography, University of Alabama-Birmingham, Birmingham, Alabama,

Consortium for Materials Development in Space, University of Alabama-Huntsville, Huntsville, Alabama,

Center for Space Vacuum Epitaxy, University of Houston, Houston, Texas,

Center for Space Processing of Engineering Materials, Vanderbilt University, Nashville, Tennessee.

In July, 1987, NASA reported that 58 U.S. corporations were CCDS participants, along with 22 universities and six Government agencies other than NASA.[15]

FOREIGN ACTIVITY

European Space Agency

The European Space Agency (ESA) has an established MRPS program. The first phase (1982-1985) had three elements: (1) development of multi-user facilities for biological experiments on the Spacelab, (2) developing a fluid physics module to study hydrodynamics of liquids in microgravity, and (3) using the West German and Swedish sounding rocket programs to conduct microgravity experiments in preparation for longer duration missions on-orbit. The second phase of the program (1985-1989) had as its original focus the use of the Shuttle and deployable facilities for longer duration experiments. The STS flight of the SL-1 Spacelab mission was primarily an ESA mission, with heavy emphasis on microgravity research. The combined number of microgravity experiments flown on the SL-1 mission and the German Spacelab D-1 mission was equal to the total number of American experiments flown on 21 Shuttle flights.[16] Since the Challenger accident, ESA has resorted to the use of sounding rockets for additional testing until the Shuttle resumes its flight schedule.[17]

In the coming years, the Europeans plan to rely heavily on the ESA Spacelab and the SPAS, EURECA and MTTF free flying facilities, as well as follow-ons such as the Columbus module for use with the U.S. international Space Station, for on-going space-based MRPS research. These facilities and their capabilities are described in the Section entitled Space-Based Industrial Facilities.

Federal Republic of Germany

In addition to its participation with ESA, the Federal Republic of Germany (West Germany) has pursued its own microgravity research programs. The German government, through the German Space Agency DFVLR has already sponsored one STS flight of Spacelab D-1 mission in October 1985 (at a cost of $130 million) and plans a follow-on Spacelab mission for 1989. In addition, the BMFT (Ministry of Research and Technology) has contributed substantially to the TEXUS microgravity research program, which was established to stimulate scientific and commercial interest in MRPS activities. At least one private venture, INTOSPACE GmbH, has also been established to promote industrial MRPS activities.

TEXUS is a comprehensive microgravity research program that relies heavily on the use of sounding rockets. Its membership includes most ESA member countries and Japan. Initiated by the German Ministry of Research and Technology, it is now being turned over to the MBB-ERNO consortium as a commercial operation. MBB-ERNO has already fully booked four sounding rocket launches for 1988 with microgravity experimenters, with users paying full cost for the launch services.[18]

INTOSPACE is a consortium of companies, primarily West German, established to coordinate and promote industrial activities in microgravity research and applications. As part of its function, it will aggregate users with similar requirements for group use of launch vehicles and space facilities such as TEXUS, SPAS, EURECA and Spacelab. INTOSPACE was founded by MBB-ERNO and Aeritalia. Other major shareholders include Dornier Systems, Kayser-Threde, Daimler-Benz, Volkswagen, Keinbaum International, a number of chemical companies, and banks. In all, there are 94 shareholders from nine European countries.[19]

Many of the experiments undertaken in the TEXUS program have been followed up with additional experiments on STS flights of the European Spacelab. Of the more than 80 experiments flown on the Spacelab D-1 mission, 90 percent belonged to West Germany. All but four of those experiments were successful. With this single mission, Germany made substantial strides towards a leadership position in microgravity research.[20] The Spacelab D-2 mission, also devoted largely to microgravity research, is currently scheduled to fly on the STS in 1989.[21]

France

France, through its national space agency, the Centre National d'Etudes Spatiales (CNES) maintains an aggressive national MRPS program in addition to its contribution to the ESA program. It spends close to $30 million annually on MRPS projects, an amount comparable to NASA's MRPS budget.[22] The French have participated in joint ventures with NASA, West Germany and ESA as well as the USSR. Cooperative experiments in crystal growth and solidification have been conducted on Soviet manned laboratories with further Franco-Soviet projects planned.

Japan

Japan has carried out MRPS research on the U.S. Skylab and Space Shuttle, the European Spacelab, and Japanese rockets. It plans to continue using these facilities in the future, as well as the international Space Station and associated free-flyers for additional MRPS research. Private companies in Japan bear approximately 80 percent of Japan's total research costs.[23]

Five groups of Japanese companies have been organized to study the prospects for commercial use of the space environnment. Altogether, these groups comprise more than 250 companies from Mitsui, Marubeni, Mitsubishi and Nissho Iwai. One of these groups, the Society for the Study of the Commercial Use of the Space Station, is concentrating on developing methods to produce thin diamond films in microgravity for semiconductor substrates. The 45 companies involved in this group, including Mitsubishi Heavy Industries, intend to use NASA Get Away Special (GAS) cannisters on the Space Shuttle to conduct microgravity experiments as a first step toward full-scale commercial production in space-based facilities.[24]

People's Republic of China

The People's Republic of China has begun conducting microgravity research within the last several years. The People's Republic reportedly conducted orbital microgravity tests for the first time in mid-1987 with a five-day orbital mission using a returnable capsule launched by a Long March II vehicle. At least five substances were solidified and retrieved during this mission.

Soviet Union

The Soviet Union has placed major emphasis on MRPS research and development, and has given it high priority aboard the Soviet Space Station. To date, the U.S.S.R. has conducted more than 1500 experiments in MRPS with a projected 2500 to be completed by 1991.[25] The U.S. has conducted fewer than 100 MRPS experiments to date, and will not have the capability to increase this number substantially before 1991.[26] Although it is difficult to make a comparison of technological capability on the basis of these numbers, the chances for advancement in MRPS research increase with the number of opportunities for experimentation. The Soviet Union has also developed a variety of MRPS furnaces for crystal growth.[27]

POTENTIAL DEMAND

The lack of routine access to space is the primary impediment to MRPS research and potential commercial opportunties. Once the issue of access is resolved, the cost of space-based production will be a primary determinant of demand. Costs include transportation to and from orbit, developing and building MRPS hardware capable of operating in the space environment, and insuring against risk of loss. The costs of space-based production, along with the quality of the products produced in space, must be compared with the cost and quality of similar products that are manufactured on earth. Despite the current impediments to MRPS, companies representing a range of interests believe MRPS has direct economic potential and that the results of MRPS research can be used to improve ground based products and processes.

Most pharmaceutical companies have expressed interest in conducting MRPS research. Companies that have already engaged in some research include Smith, Kline and French; Burroughs-Wellcome; Schering-Plough; Merck and Upjohn. Examples of pharmaceuticals that might be commercially produced in space despite the high costs of production include a human growth hormone, bothropsinase reagent, human pancreatic chymotrypsin and parathyroid hormone.

One promising near term space market is the growth of protein crystals that are larger and higher quality than those produced on earth. Such crystals are essential in protein crystallography, a technique used to determine the atomic structure of proteins. Understanding their structure is a critical step toward being able to manipulate the composition and actions of proteins, for developing new drugs, chemicals and other products. There are approximately 250,000 protein types, of which the structures of only 300 are known. A recent survey conducted by the Harvard Business School determined that companies using protein crystallography techniques in their research (mainly pharmaceutical, chemical and biotechnology companies) would pay between $100,000 and $200,000 for a single protein set of eight to ten crystals.[28] Recognizing that a number of protein crystal growth (PCG) facilities could eventually be established in space, Wyle Laboratories projects that the PCG facility planned for the U.S. international Space Station could process 720 crystal sets every 90 days.[29]

Other promising areas of MRPS include high quality semi-conductors, metallurgical products, pure glass, ceramics and plastics. The annual market for earth-grown semiconductor crystals is growing at approximately 30 to 50 percent per year, and is expected to reach $1.8 billion by 1992. Worldwide, more than 40 tons of "exotic" semiconductor crystals, primarily gallium arsenide, were grown in 1986, with a market value of over $80 million. The demand for cadmium telluride, another emerging semiconductor material, is currently estimated to be $20 to 25 million and is expected to double annually for the next four years. The market for indium phosphide, another emerging electronic material, is estimated at $30 to 35 million per year, and predicted to grow to more than $100 million by 1990.[30]

Semiconductor crystals that can be produced in space are projected to comprise 5 to 8 percent of the market in terms of dollars by 1995.[31] Space crystals will be more expensive than those produced on Earth, but may yield higher performance. For example, space grown crystals may permit greater electron mobility, the size of the crystal may be larger, etc. The high cost of space-grown crystals may be offset by their expected higher quality and higher yield. Space-grown crystals are expected to be utilized in very high performance devices. This means that space crystals will compete only for the high quality end of their respective markets, leaving the lower quality materials grown on earth to retain their current market niches.

Metallurgical products are also high on the list of expected MRPS markets. According to various reports, hundreds of space-unique metal alloys have been identified to date. Major companies such as Bethlehem Steel, Alcoa, Ford, Inco and General Motors have conducted space materials research for some time. Similarly, the commercial potential of MRPS is being explored by companies like 3M for organic crystal materials, Crystallume Inc. for pure glass materials, and the Hoechst-Celanese Corp. for ceramics and plastics.

The market for materials furnaces and ancillary crystal growth support equipment is projected to sustain a 20 to 30 percent annual growth rate through 1990.[32] Worldwide gross shipments of crystal growth technology in 1986 were more than $350 million, with the portion pertaining to furnaces estimated at more than $150 million.[33] The market for space applications furnaces is growing, but among other things is inhibited by lack of routine, affordable access to space. Potential customers include government and private organizations in need of such technologies. Present estimates place this market at $5-8 million annually, growing to more than $20 million by 1990.[34]

GROUND-BASED ACTIVITIES

U.S. COMMERCIAL ACTIVITIES

The Challenger accident and subsequent uncertainty regarding access to space has caused U.S. companies to shift concentration to ground-based research programs. The objective of ground-based materials research is to maximize information return from past MRPS activities, and to advance knowledge through ground-based projects until routine and affordable access to space is available. Even before the Challenger accident, about 90 percent of microgravity research was ground-based in preparation for the 10 percent done on orbit. Despite the percentages, however, the space-based portion of the research is considered to be the more valuable by far.

The information gained from space-based microgravity research has opened new commercial opportunities for firms engaged in ground-based materials processing. For example, International Space Corporation has used this information to develop ground-based furnaces that are expected to produce superior quality cadmium telluride crystals. The company also plans to use space-grown crystals as "seed material" for ground-based crystal production as an interim step towards full commercial space-based production.[35]

In its three years of preparations for spaceflight, MRA has made considerable progress with its novel crystal-growth technique. As a result, MRA has now demonstrated and published the results on the growth of bulk quantities of gallium arsenide, other III-V compounds and their ternaries and quaternaries. The quality of the bulk compounds has been equal to the quality of the best epitaxial layers; that is to say, near perfection.[36] MRA now seeks to go to space solely to increase crystal diameters. It also plans to establish an earth-based production facility to produce laboratory samples of its novel materials.[37]

VI. INSURANCE

Insurance has been and will continue to be an essential element in the development of space commerce. U.S. companies involved in commercial space ventures will have substantial amounts of capital at risk, property exposed to loss and corporate operations and products exposed to legal liability. Insurance provides the contractual mechanism for reducing uncertainty in business activity by transferring the risk of loss to insurers organized to take such risks. From a financial standpoint, insurance, if available in sufficient quantity and at reasonable cost, can remove much of the fortuitous risk, leaving the investor with normal commercial risk. The commercial practicability of space related activities will depend heavily on how effectively and consistently risk of loss can be transferred through insurance.

To date, most private sector space ventures have been in the communications satellite sector. Most commercial and foreign communications satellites launched into space have been insured during at least the launch phase for the value of the satellite and launch services, and for legal liability in the event of injury to third persons and damage to their property. In addition, a number of satellites have been insured against premature operational failure. As space business develops into other areas, such as transportation, remote sensing, materials processing and multipurpose use of orbital platforms and space stations, insurance will continue to play a vital role.

THE INSURANCE INDUSTRY

The insurance industry is composed of brokers and insurers. The broker's role is to tap the available capacity from primary insurers and reinsurers. There are a number of different types of primary insurers, some of which are more active in the space sector than others. Three major types of primary insurers include insurance companies underwriting on their own behalf, groups of insurance companies who have combined their capacity, with underwriting performed by a managing general agent, and Lloyd's syndicates, who underwrite insurance risks on behalf of their individual members.

Reinsurers assume much of the ultimate risk of loss by providing insurance to the primary insurers, thereby sharing the risk among a broader group of risk takers. Reinsurance can be prearranged between insurers and reinsurers in an agreement called a "treaty". Alternatively, it can be established on an ad-hoc or "facultative" basis. The extent to which space risks attract sufficient reinsurance determines the ultimate success in achieving the requisite amount of insurance capacity at reasonable cost.

Space insurance capacity is provided primarily from U.S. and European sources. Principal U.S. underwriters to date have been International Technology Underwriters and U.S.A.I.G. More than half of all space insurance is placed with underwriters in Europe. Principal European underwriters to date have been

Lloyd's of London (U.K.), Generali (Italy) and Munich Reinsurance (W. Germany). Combined U.S. and foreign capacity will continue to be important to commercial space projects. Major brokers of space insurance to date have been Corroon & Black Inspace, Marsh & McLennon, Johnson & Higgins, Frank B. Hall, and Nausch, Hogan & Murray.

KINDS OF INSURANCE COVERAGE

The three basic kinds of insurance coverage are first-, second- and third-party insurance. First-party insurance covers losses incurred by the insured to its own property or personnel. For example, this kind of insurance covers the loss of a communications satellite by the satellite owner if it fails to achieve orbit or it malfunctions. It may also cover resulting loss of profit or business interruption costs.

Second-party insurance covers the policy holder for damages caused to a second, related party. For example, a launch service provider contracting with the U.S. Air Force (the second-party) for use of Government launch facilities and related range services would be liable for damage to Government property caused by the launch vehicle. The launch service provider could also be liable to its customer, the satellite owner, or to the satellite insurer through subrogation, if the launch vehicle malfunctions and destroys the satellite payload.

Third-party liability insurance provides protection from liability incurred by the insured as a result of harm or damage caused to unrelated third parties. This kind of "innocent victim" coverage would apply if, for example, a launch vehicle, carrying several hundred tons of explosive propellants, malfunctions, and its consequent destruction at low altitude causes injury or damage to a nearby community.

SPACE ACTIVITIES AND THE ISSUE OF LIABILITY

There are both international and U.S. domestic issues of liability that must be considered.

INTERNATIONAL LIABILITY ISSUES

The United States is a Party to two international treaties governing liability for damages caused by space-related activities: the Treaty On Principles Governing The Activities Of States In The Exploration And Use Of Outer Space, The Moon and Other Celestial Bodies (1967 Outer Space Treaty)[1] and the Convention on International Liability For Damage Caused By Space Objects (Liability Convention).[2] The Treaties make each of the member States liable for their space related activities, and do not impose any limit on the amount of liability that can be incurred. They do not, however, establish or govern the liability of the respective member states to their own nationals.

The significance of these Treaties to the U.S. commercial space industry is that the U.S. Government is liable to other member States and their nationals for all

U.S. space-related activities carried out by non-governmental entities over which it has jurisdiction. When such activities are carried out by international organizations, responsibility for compliance with the Treaties is borne by the international organizations if they have adopted the Treaties, and in any event by the States party to the Treaties that are members of the organization.

The Liability Convention does not address the internal procedures for States to meet their international obligations. The U.S. Government has the right, under law, to recoup damages caused by non-governmental entities for which the Government is held liable. It may waive that right to recover from its own nationals, resulting in a Government indemnity of sorts. However, the U.S. Government's waiver in this case does not preclude foreign nationals from suing outside the treaty, for example, a U.S. launch service provider whose rocket causes the damage. The issues of relative liabilities among American space-related businesses, the Government, and other involved parties must be addressed on a national level.

U.S. DOMESTIC LIABILITY ISSUES

Prior to the Challenger accident in January 1986, commercial payloads in the United States were launched by NASA, pursuant to standard Launch Service Agreements (LSA).[3] The LSAs contain liability provisions in accordance with the NASA Act, the Federal Acquisition Regulations, the Federal Tort Claims Act and state law. The subsequent initiation of private sector launch services has generated new issues regarding liability and insurance coverage. The following discussion highlights some of the existing issues attendant to both NASA sponsored space activities and those of the private sector.

NASA Launch Services

Despite the current policy to remove commercial payloads from future Shuttle flights, there will continue to be a limited amount of commercial activity and payloads on the manifest for "Shuttle unique" payloads and payloads affecting foreign policy and national security.[4] The insurance requirements for these payloads will continue to be subject to Federal and state law, and the conditions set forth in the NASA LSA.

The NASA Act gives the NASA Administrator the authority to provide third party liability insurance for any user of a space vehicle, taking into account the availability, cost and terms of private liability insurance.[5] Further, the Administrator may indemnify the user against claims by third parties to the extent that such claims are not compensated by the liability insurance of the user.[6]

Further, the Code of Federal Regulations for NASA exempts the Government from damage to a payload or harm to a payload specialist through the fault of the U.S. Government, its contractors, or other STS users. The user must assume that risk or obtain insurance protection against it.

The NASA Launch Services Agreement for commercial or other private users of the Shuttle contains several important provisions relevant to liability. Specifically, it: (1) requires commercial users of the Shuttle to procure the limit of reasonably available third party liability insurance, with the Government as a named insured, (2) provides indemnification by the Government in excess of the insured amount, (3) requires comprehensive cross waivers among all parties, including the Government, to eliminate liability for respective parties' property interests, and (4) provides re-launch options in the event of payload loss.

Private Sector Launch Services

With U.S. private sector companies now beginning to conduct their own commercial launch operations, the Commercial Space Launch Act of 1984 has taken on new importance.[7] It provides, in part, that the Secretary of Transportation may establish requirements for liability insurance, hold harmless agreements and proof of financial responsibility. Additionally, the Secretary must establish a minimum liability insurance level for commercial space launch operations, taking into account the international obligations of the United States in this regard. Although the Secretary may require the private sector to indemnify the Government and shall prescribe the amount of liability, he or she must do so consistent with the goal of promoting and facilitating the commercial development of space.[8]

In addition, the Air Force and NASA have developed Model Agreements to set forth terms for use of U.S. Government properties, facilities, goods and services.[9] These agreements include provisions concerning responsibility for damage to Air Force, NASA, and other U.S. Government property, as well as third party liability.

The Air Force Model Agreement requires the User to assume responsibility for all damages to its own property, and also to assume responsibility for the property of the U.S. Government and its contractors or subcontractors, regardless of fault, to the extent of the maximum available insurance worldwide at reasonable cost, for any specific launch.[10] The Model Agreement also requires the user to assume all third party liability that might result from a launch, including liability of the U.S. Government, its contractors and subcontractors, up to the level of maximum available insurance, regardless of fault and without regard to any insurance exclusions, for example, latent environmental risks.[11]

According to the Air Force Agreement, "Maximum available insurance" means that which "is available in the world market at a reasonable premium and on terms considered commercially reasonable for the risks involved to fund the User's responsibilities under this Agreement."[12] The responsibility for determining the maximum amount of insurance available and the reasonableness of the price for that coverage is left to the U.S. Government and that determination cannot be appealed..[13]

The Air Force Model Agreement states that responsibility of paying any claims in excess of that maximum available amount is to be determined by applicable U.S.

law including the Federal Tort Claims Act, and the Government reserves the right to pursue claims against the user or any other party for damages exceeding the user's insurance.[14] It also states that all U.S. Government property is to be furnished "as is" and the U.S. Government makes no warranty whatsoever regarding its property.[15] The User may not make any claims against the U.S. Government or its contractors or subcontractors for damage caused by any range safety actions and shall indemnify the U.S. Government against any claims made against the U.S. Government resulting from such actions.[16] The provisions in the NASA Model Agreement are similar to the Air Force Agreement in most respects.

CURRENT SITUATION

PROPERTY DAMAGE

Prior to 1977, the insurance industry experienced approximately ten years of modest profit from commercial space ventures. Between 1977 and 1982, five major insured satellite losses occurred. Some insurers were untouched and others were adversely affected. Then, beginning in 1984, a run of nine more insured satellite losses severely reduced the available insurance capacity in the world market. These disasters increased cumulative losses to more than $1 billion, with less than half of this amount collected in net premiums to insurers. The commercial launches since 1984, which account for only 20 percent of the total number, have resulted in 70 percent of all space insurance losses. On top of this, the loss of the Space Shuttle Challenger, although not producing an insurance loss, left a vivid impression that space operations are not free from catastrophic failures.

Currently, an estimated $100 to 150 million in insurance capacity is available worldwide to cover a single satellite launch. This amount is down from about $250 million four years ago. Combined risks in the case of dual satellite launches would have to split the capacity. The premium cost is on the order of 20 to 25 percent to cover a communications satellite from ignition of the main rocket engines on the ground through the ascent to geostationary orbit and initial checkout and operation of the satellite (the insured on-orbit checkout period lasts approximately six months). Specific terms and conditions of the coverage affect the rate, as do the particular mission and systems characteristics.

THIRD PARTY LIABILITY

There have been no third-party claims paid under either a launch liability policy or manufacturer's aerospace products liability policy. Nevertheless, the current legal and regulatory environment exposes companies to potentially unlimited third party liability in the event of a catastrophic accident. This unbounded exposure is a real concern to companies involved in space-related activities.

How well manufacturers and their subcontractors can protect against third-party liability during space related activities will in many cases affect their willingness to supply space systems in the future. Aerospace manufacturers are accustomed to carrying coverage of $500 million to $1 billion for all their products, but recently insurers are specifically limiting spacecraft products coverage. With the transfer of commercial launch responsibility from NASA to commercial carriers, new exposures have followed, without benefit of any potential for Government indemnification under P.L. 85-804 or Section 308 of the NASA Act. Unlimited third party liability exposure has generated uncertainty and concern over the amount and scope of available insurance.

Martin Marietta has signed the Air Force Model Agreement, and General Dynamics signed the NASA Model Agreement. The unlimited third-party liability exposure these companies have assumed under the Model Agreements has been termed by the industry as "betting the company."

FOREIGN LAUNCH SERVICE INSURANCE PACKAGES

Foreign launch service providers have taken a significantly different approach to the problems of property damage and third-party liability. In most cases, third party liability is "underwritten" by these competitors through a government sponsored combination of guaranteed insurance and indemnification in excess of insurance coverage. With respect to liability for damage to launch facilities and associated property, comprehensive cross-waivers relieve the parties involved in the launch of any liability to each other for damage to their respective properties.

ARIANESPACE

Arianespace requires mutual indemnification and cross-waiver agreements, similar to the NASA LSA, as well as indemnification from its customers in the event Ariane is sued as a result of customer-fault or failure of the customer to secure a needed waiver.

Arianespace offers its commercial customers insurance packages through its wholly-owned subsidiary, S3R. This new service offers launch customers optional coverage for risks incurred from launch until time of spacecraft separation into the required orbit. Designed to cover part of the customer's financial risk, this guarantee is linked to the payment schedule of the main contract, and is available at contract signing at predetermined rates.[17]

Arianespace provides third party liability insurance up to 400 million French Francs (approximately U.S. $50 to $60 million). The French Government provides indemnification for any claim of a third party in excess of this amount for a period of 36 months from time of launch. After that period, any damages sustained by third parties attributable to the operation of the user's spacecraft becomes the responsibility of the user. Arianespace also provides significant protection against launch failure through its "Launch Risk Guarantee Agreements". These agreements offer protection equivalent to that available from commercial insurers, at lower rates, in an amount equal to the launch cost.

PEOPLE'S REPUBLIC OF CHINA

The People's Insurance Company is currently offering $60 million of launch risk insurance for the Long March vehicle user at a discounted premium rate. The Chinese have also offered to indemnify against third party liability.

SOVIET UNION

In addition to the very low price for launching a commercial communications satellite on the Soviet Proton ELV, Glavkosmos and the Soviet Licensintorg are offering reflight or refund insurance at very low rates. The Soviet insurance agency Ingosstrakh has stated that it is likely that it would impose a charge on the commercial user for third party liability insurance coverage, but the government would provide indemnity in excess of the insurance.

U.S. INDUSTRY ASSESSMENT OF THE SPACE INSURANCE MARKET

The following section represents a distillation of current industry views on factors affecting the commercial prospects or viability of this industry sector. The industry concerns presented here have been expressed during the last year to the Department of Commerce through briefings by more than 100 companies covering the entire range of commercial space activities.

The views expressed here are those of space industry representatives and do not necessarily constitute policy recommendations by the Department of Commerce. This section is intended to provide a basis for more informed discussion of these issues. Where a diversity of industry views exists, an attempt has been made to present the various industry views in a balanced manner.

The likelihood of damage or liability occurring during the launch phases is the most often discussed element of assessing insurance exposure. Industry representatives have stated that the elimination in the Model Range Agreements of the comprehensive cross-waivers, in addition to the imposition of unlimited third-party liability exposure, could seriously affect insurance availability and cost. They have also stated that subcontractors to launch service providers, as well as to their satellite customers, are being affected by a growing tendency to exclude space risks from products liability insurance upon which these subcontractors depend.

The availability of sufficient capacity to cover potential losses is dependent on the size of the potential market from which premiums will be derived. The tendency to compare the airline industry to the commercial space industry fails on this issue. Even worldwide, the potential number of launches and payloads in a given period is vastly smaller than the number of airline flights which occur during the same period. The result is that the relatively small number of space related activities that occur during a given period require the premiums for space-related insurance to be large in order to reasonably assure a net profit.

Since the inception of space-related insurance, the differential between premiums paid and losses accrued has resulted in a net loss for the insurance industry of approximately $500 million. Accordingly, commercial insurance capacity has declined while premiums have risen from 5 to 7 percent in the early 1970s to between 20 and 25 percent today for launch risk coverage. That reduction of capacity and increase in premium rates is having a profound impact on both commercial ELV service providers and on long-range planning for major space hardware projects.

Industry representatives from all sectors including the ELV industry, communications satellite companies, remote sensing companies and on-orbit hardware manufacturers have stated that the current lack of firm premium quotes and guaranteed availability of coverage has deterred investors from committing necessary capital to space-related projects.

Representatives from the insurance industry have stated that a series of successful flights would increase the current capacity for launch risk insurance. They have also predicted that premiums have reached peak levels and should retreat slightly in the absence of further failures.

Insurance industry representatives have stated that the issue of third party liability, and the new and unlimited responsibility for damage to Government property, will not be resolved with the resumption of flights. In the opinion of representatives from all commercial space sectors, some action must be taken to relieve U.S. companies from such unlimited liability exposures for U.S. launches. The general consensus is that failure to do so will prevent U.S. ELV companies from competing with foreign launch service providers and achieving long-term viability.

In addition to the impact on existing and potential investors, the questions of insurance cost and availability may begin to shape future hardware programs. Insurance representatives have stated that technological developments leading to more sophisticated, complex and costly space systems may be uninsurable. To that extent, the current insurance "crisis" could dictate technological development in the space industry.

According to representatives of the insurance industry, the launching of commercial satellites and other space goods by the private sector introduces exposures to space hardware suppliers that were previously eliminated by the rules and regulations for launches conducted by the Government. Examples include the Limitation of Liability clauses contained in the Federal Acquisition Regulations and the comprehensive inter-party waivers in the NASA Launch Services Agreement (LSA). In this context, industry representatives have stated that the elimination and/or changing of any government protections or hold harmless agreements must then be assessed by the insurance community. Should new exposures be found uninsurable or previous protections impossible to duplicate, they have stated that the space hardware supplier community must be advised that a new insurance situation exists.

VII. FINANCE

The financial community looks for investment opportunities that will provide a reasonable return on investment, given the level of risk, in a reasonable time-frame. Space-based ventures generally are weighed by potential investors against alternative ground-based opportunities. Commercial space ventures have been characterized as capital intensive, with long lead times and long payback periods. Nevertheless, the financial community has participated in ventures involving communications satellites and launch vehicles, because the projected risk-adjusted return justified the investments.

The financial community has not been so willing to participate in less developed space-based businesses, such as materials processing and space-based industrial facilities. In these markets, financial assistance has come primarily from wealthy individuals through tax benefits driven R&D partnerships, and direct corporate funds where the technology and experience gained contributed to investment motivation. Government cooperative ventures, such as the NASA Joint Endeavor Agreements, have facilitated investment by reducing the required entry investment.

As the technologies for these markets mature and the associated risks diminish, the financial community is likely to become more supportive of commercial space ventures. The financial community will consider each investment opportunity on its own merits, be it earth or space-based, choosing those that represent the best profit potential with acceptable risks.

BACKGROUND

Industry's overall financing capability vastly exceeds the needs of any one commercially practicable space venture. For example, total corporate non-financial investment raised in 1986 was $542 billion. In some individual "mega-financings", such as Beatrice Companies, Inc., leveraged buyouts have exceeded $6 billion.

The financial vehicle(s) used in a particular project depend upon: risk, length of time for return on investment, size of the project, growth expectations, etc. The general types of funding for projects in descending order of risk are: direct corporate investment; institutional and privately marketed equity; limited partnerships, public equity; bank loans; and public or securitized debt. Each is described below.

Direct Corporate Investment: This type of funding most often covers projects involving exotic risk. Such investments may have long lead times or they may offer returns that are not easily quantified, such as benefits gained from experience and the development of new technologies. Such projects may be oriented to developing strategic opportunities. This type of funding can vary from small to large multi-million dollar consortium financings.

Institutional and Privately Marketed Equity: This type of funding involves selling shares in a company to groups or individuals. Venture capital is a subset of equity financing. Venture capitalists provide capital to assist companies with viable new products or services through the risky, early years of development and growth in anticipation of taking the company public. They tend to look for a payback period of from three to five years through a public offering. The investment size is usually well under $50 million.

Limited Partnership: This mechanism, which centers on the use of funds from a group of investors, is often used for developing and marketing a new technology. It has the size limits for funding of privately marketed equity. It can serve to limit, however, the ability of the user of the technology to shift to different technologies if the user's market shifts.

Public Equity: Most large companies are funded primarily through equity financing, with shares traded publicly either on one of the stock exchanges or on over-the-counter markets. Occasionally, this sort of funding will also be used for companies that have not yet generated revenue, in cases where the prospect for profitability is thought to be great. Earlier offerings tend to be smaller than for more mature situations.

Bank Loans: Bank loans are usually available for mature companies when cash flow is reasonably certain, the borrower has an asset that can reasonably expect to generate cash during the normal course of business, or in early phase of development, there is support for the obligation from a strong, credit-worthy organization. Lenders generally do not bet on the success of the business for repayment. Rather, their decisions are generally based on indices of the borrower's credit-worthiness.

Public or Securitized Debt: This type of funding is reserved for well established companies or situations where support of the debt is provided by well established parties.

The financial community is supported by the services of other professional groups, including lawyers and accountants, as well as technical, economic, and political analysts. Financing decisions are based on information provided by reputable experts who advise investors about the feasibility of a specific project. As this pool of experts expands, the financial community will become less reluctant to commit funds to space related ventures thought to be commercially viable.

WORLDWIDE FINANCIAL MARKET CHARACTERISTICS

In order to attract financing, space-related activities must offer returns on investment that are at least competitive with ground-based investment opportunities. Similarly, the perceived risks in space-related activities must be balanced by their profit potential, and ideally, no greater than ground-based alternatives.

Most financing sources will take risks on the performance of a company's management, customer's acceptance of the services to be provided, or the future condition of financial markets. Lenders or investors will not generally take large "exotic" risks such as the chance of an uninsured successful launch, a technical breakthrough, or the need for a major change in the legal environment to make business viable after a major investment has been made.

Some technically feasible activities may not be commercially viable because poor returns are expected. An example of this is the attempt to establish direct broadcast satellite services in the early 1980s, when the commercial concept was substantially ahead of the market. Many space-based applications may not be commercially practicable because capital costs are too high. The ultimate market revenues may not be large enough to support the high capital costs.

SPACE MARKETS

The space industry is made up of a series of markets, all with differing stages of maturity and each with a unique set of technical requirements. As a result, the response from the financial community has been market specific.

U.S. Markets

Satellite Communications

Since the early 1960s, the financial community has supported the development of both ground- and space-based hardware and services for the communication satellite industry. All of the available funding mechanisms have been used to support various satellite ventures at one time or another. The commitment of the financial community still exists, though investment decisions by corporate sponsors are now more conservative due to increased competition from fiber optic cables and the uncertain status of the space transportation industry. Geostar corporation, for example, has raised more than $50 million from over 500 shareholders, managed funds (pensions) and private investors.

The latest example of major financing in the communications satellite area is the arrangement completed by Citibank, Lazard Freres, Ltd., and Salomon Bros. International for the financing, construction, launch and operation of a commercial Direct Broadcasting Satellite (DBS) system for the United Kingdom. The critical component of this deal is the agreement by the satellite supplier to assume the launch risk by agreeing to deliver the satellite "on orbit," operating to specifications.

Tax-oriented leasing, or sale/lease-back arrangements, have been utilized on a number of occasions as a funding source in the communications satellite sector. The leasing involves three parties: a satellite owner/operator, an equity investor and long-term lenders, usually commercial banks. The equity investor contributes 20 to 30 percent of the satellite cost, taking title and tax benefits in return. The long-term lenders contribute the balance of the cost, and take a security interest in the asset. The satellite owner/operator sells the asset to the equity participant, thereby financing the acquisition, and then leases back the capacity of the satellite under a long term lease, with installment payments that reflect the tax benefits accruing to the equity participant. Although tax reform has eliminated the investment tax credit, which was a major financial attraction to sale-leaseback arrangements, it has provided a balancing attraction by permitting a shorter write-off period for accelerated depreciation.

Space Transportation

Of all the commercial space sectors, the space transportation market is currently the most carefully watched by the financial community. Although the market for large capacity class satellites is occupied in the United States by established entrants (Martin Marietta, McDonnell Douglas and General Dynamics), small capacity and sub-orbital cargoes present new commercial opportunities yet to be exploited. The grounding of the Space Shuttle has created a backlog in all payload classes. Even prior to the Challenger accident, the financial community was beginning to respond to the market for small capacity class cargo through investment in several entrepreneurial ventures. After the accident, the Administration's decision prohibiting the use of the Shuttle to transport non-Shuttle unique commercial cargo eliminated the prospect of the Government using the Shuttle as a competitor to private sector space transportation efforts. As a result, a number of private sector companies are now vying for that business.

For the financial community, the backlog of payloads that can be flown on commercial ELVs represents a measurable demand. The capabilities of the various ELVs on which commercial space transportation is offered is a measurable supply. As a result, firms such as Conatec, E' Prime, Space Services, Inc. and American Rocket Company have raised varying amounts of private sector capital in order to deliver sub-orbital and small capacity class cargo into space.

Satellite Remote Sensing

The involvement of the financial community with the remote sensing market must be divided into two main components: (1) space and ground segment hardware development, and (2) the value-added industry. In the case of hardware development, the financial community has had only limited involvement. This is due largely to the inability of the private sector to compete against the government-supported Landsat satellite system, operated and marketed by EOSAT. EOSAT is a partnership of General Motors/Hughes Aircraft and General Electric Corporation.

The private sector has taken a stronger interest in funding the development of value-added ventures. In the last year, the Eastman Kodak Company, for example, began its own value-added venture, with a combination of both internal funds and outside financing. The attraction of the value-added industry to the financial community is the ability to predict market demand, based on prior patterns of purchase and expected future trends. There is a strong belief in the financial community that demand for remote sensing data will grow significantly over the next 10 years, as new remote sensing satellites, mostly foreign-owned, are deployed, and as computers required for value-added services continue simultaneously to decrease in cost and increase in capability.

Space-Based Industrial Facilities

All of the current proposals for commercially developed space facilities share two common traits of concern to the financial community. Each is capital intensive on the order of hundreds of millions of dollars and each is largely dependent (at least in current design) on the availability of the Space Shuttle for development and servicing.

The size of the required investment eliminates a reliance on wealthy individuals for other than first-stage financing. A number of the industrial facility ventures, including SPACEHAB, Space Industries, Inc. and External Tanks Co., have been successful in raising investments from wealthy individuals as a first stage investment strategy. However, to date, only Space Industries Partnership has moved on to the second stage, bringing in Westinghouse and the Boeing Corporation as corporate partners.

The participation of Westinghouse and Boeing demonstrates that major U.S. companies are willing to participate in private space ventures, particularly if the projects are consistent with the company's long-range business strategy. The investment in Space Industries Partnership makes good business sense for Westinghouse, because the Industrial Space Facility will rely heavily on robotics and artificial intelligence systems. Westinghouse is currently a leader in industrial application of these technologies. Boeing's participation in the venture is based on current complementary activities and long-term strategic positioning interests.

The Administration's decision, as part of the President's Commercial Space Initiative, to lease a portion of the space available on a commercially developed space facility for a minimum of five years, is critical to the willingness by the financial community to underwrite the venture.

Materials Research and Processing in Space

When the Shuttle program was operational, the financial community was willing to participate in materials processing ventures. Firms such as Microgravity Research Associates and International Space Corporation were able to raise several million dollars for first stage financing. Internally funded programs were established by numerous companies, including McDonnell Douglas, Boeing, Grumman, and John Deere. Perhaps the best known effort was McDonnell Douglas' joint venture with Ortho Pharmaceuticals to manufacture high-quality pharmaceutical products in space.

Since the Challenger accident, however, there has been a considerable amount of uncertainty among industry participants concerning the ability to obtain near-term access to space. Both basic and applied research in the microgravity environment requires routine access to space and a facility for extended research and production. The lack of either of these at the present time has made it virtually impossible to obtain financing, both commitments by large corporations of internal funds and efforts by entrepreneurial organizations to get outside investor support.

Foreign Markets

It is difficult to compare the involvement of the U.S. financial community with that of other countries, where much of the funding comes from the government. In Europe and Japan, for example, multi-year government funding for long-term space programs provides the private sector with some degree of assurance that a specific program will reach fruition. As a result, the private companies are more inclined to invest in new ventures that are complementary to government programs.

FINANCIAL IMPLICATIONS OF U.S. COMMERCIAL SPACE ACTIVITIES

The following section represents a distillation of current industry views on factors affecting the commercial prospects or viability of this industry sector. The industry concerns presented here have been expressed during the last year to the Department of Commerce through briefings by more than 100 companies covering the entire range of commercial space activities.

The views expressed here are those of space industry representatives and do not necessarily constitute policy recommendations by the Department of Commerce. This section is intended to provide a basis for more informed discussion of these issues. Where a diversity of industry views exists, an attempt has been made to present the various industry views in a balanced manner.

Between 1980 and 1986, the U.S. private sector invested more than $300 million in emerging space markets (not including satellite communications). Since that time, the dollar amounts have increased by another $500 million, in large part due to the emergence of a private space transportation industry composed of expendable launch vehicles. Major financial institutions have expressed the belief that there is nothing inherent in space business that will prevent further participation from the private sector.

Though the almost $1 billion worth of private sector capital committed to new space ventures is not large when compared to mature industries, it is significant given the many perceived risks involved in a space venture. The financial community certainly has the capability to support any private sector space effort that justifies the risk. The support already given to the space industry is a small fraction of what would be available if private ventures were allowed to compete in the space market with the Government acting not as a competitor, but as a buyer of commercially available space goods services.

The major attraction of in-space investments is the opportunity to create new markets and new industries. The opportunity to participate on the ground floor of a new industry has caused both entrepreneurs and investors to be unusually patient in their efforts to remove institutional obstacles.

Nevertheless, the major concern expressed by the financial community with regard to existing and potential space markets is that the United States has no firm policy or commitment to commercial participation in specific space initiatives. Potential space markets are opened and closed as policy decisions and funding levels change. Companies in the various space industries have voiced the following points regarding their own markets.

Satellite Communications

The major users of communication satellites believe the market will continue to grow well into the next century despite increasing competition from fiber optic cables. Most new growth will be in areas where satellites have inherent technical or economic advantages over fiber optic cables. Adding to the difficulty of competition with fiber optics are the uncertainties and costs currently associated with the development of the commercial space transportation market. These uncertainties, such as the inability of satellite owner/operators to predict with reasonable accuracy the satellite launch date or the costs associated with the venture (particularly insurance), have had significant negative impacts on their business plans and the willingness of the institutions that once supported them to continue investing at this time.

Space Transportation

The major concern on the part of the financial community towards support of the small-capacity class ELV industry is the role of the Government. The financial community, although supportive of these entrepreneurs to a limited degree, is today cautious, skeptical as to whether the Government will adhere to its policy of not competing with private sector space transportation services. If the Government would purchase launch services from the private sector like a normal commercial customer, the ELV market could quickly become a robust private sector industry. As stated earlier, one can estimate the Government demand and make financial decisions based on these projections.

Satellite Remote Sensing

The financial community will not consider a private remote sensing hardware venture as long as the U.S. Government continues its subsidization of the Landsat system. Only if the Government removes itself from ownership and operations of the space segment, and acts instead as a commercial customer of remote sensing data, will the financial community seriously consider underwriting the development and construction of a commercially owned and operated remote sensing satellite. On the other hand, the value-added sector of the remote sensing market should continue to increase in size, attracting increasing attention and interest from the financial community.

Space-Based Industrial Facilities

The major concerns expressed by the financial community towards investing in space-based industrial facilities are the dependency of these projects on the Shuttle and the concern that the government will compete against any private sector space hardware project, rather than contract for the use of the facility as a commercial customer.

Materials Research and Processing In Space

Materials research and processing in space requires routine access to space for both short and extended periods of time. The financial community will not invest in any venture at this time that is dependent upon routine access to space. As the space transportation industry matures, the financial community might reasses the materials processing ventures.

Long-Term Prospects

Financial companies have indicated that Government policies and actions have not created an environment conducive to participation in commercial space development. Yet private capital is a vital component of the space industry. Small companies need millions of dollars to begin a space venture. Larger companies are making decisions that involve hundreds of millions of dollars.

To play a major role in supporting the commercial space infrastructure, the financial community must see stable policy with the respective roles of Government and industry clearly defined. Financial sources have indicated that a firm commitment to purchase commercially available goods and services to the fullest extent feasible will significantly expand the projected commercial space market and increase potential interest in investment. They indicate that the Government commitment not to engage in activities that could compete with or preclude commercial operations (except for national security or public safety reasons), is equally important to potential investors. Finally, continuing Government research and development activities, independently and in cooperation with the private sector reduce risk and encourage increased investment.

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Centers for the Commercial Development of Space

Editor
Susan E. Walker

Centers for the Commercial Development of Space 2

Materials Processing

Advanced Materials Center for the Commercial Development of Space 5
Center for Space Processing 6
Consortium for Materials Development in Space 7
Center for Commercial Crystal Growth in Space 8
Space Vacuum Epitaxy Center 9

Life Sciences

Center for Macromolecular Crystallography 10
Bioserve Space Technologies 11
Center for Cell Research 12

Remote Sensing

Center for Mapping 13
Space Remote Sensing Center 14

Automation and Robotics

Wisconsin Center for Space Automation and Robotics 15
The Center for Autonomous And Man-Controlled Robotic and Sensing Systems 16

Space Propulsion

Center for Advanced Space Propulsion 17

Space Structures And Materials

Center for the Commercial Development of Space on Materials for Space Structures 18

Space Power

Center for Commercial Development of Space Power 19

Center for Space Power 20

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For further information on the NASA commercial programs, contact:
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Washington, DC 20546

Introduction

Centers for the Commercial Development of Space

In 1985, NASA initiated an innovative new effort called Centers for the Commercial Development of Space (CCDS). The CCDS program was designed to increase private-sector interest and investment in commercial space-related activities while encouraging U.S. economic leadership and stimulating advances in promising areas of research and development.

Today, this evolutionary government program has emerged as the flagship of the agency's commercial space activities.

NASA's nationwide network of 16 CCDSs represents a unique example of how government, industry, and academic institutions can combine resources and talent — strengthens America's industrial competitiveness.

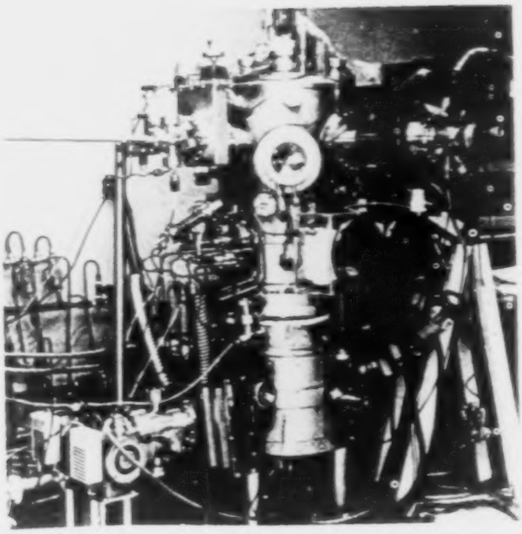
At the centers, space-based high technology research is conducted in a wide variety of areas. These areas range from remote sensing — which involves monitoring the Earth's surface to increase knowledge in areas such as crop and weather forecasting — to space-based materials processing in which the microgravity, high-vacuum environment of space is utilized to process unique, high-value products and learn more about Earth-based materials processing techniques.

By removing impediments, coordinating efforts, and encouraging private enterprise, the CCDS program helps move these emerging technologies from the laboratory to the marketplace with speed and efficiency.

In a relatively short time, these centers have made significant contributions toward encouraging and fostering greater private-sector investment and participation in commercial space ventures.

At present, CCDS affiliates include nearly half of the nation's 50 largest industrial corporations — some of which are affiliated with as many as 3 different centers.

As a new mechanism for increased NASA-industry cooperation, the CCDS program currently allows more than 125 industrial affiliates — many of them non-aerospace companies — and 51 university participants to explore the economic potential of space in this program where technical and financial risks are shared.



Space Vacuum Epitaxy Center (SVEC) research scientists built this unique high-vacuum chamber for high-temperature superconductor thin film growth. Ground-breaking research is being conducted in the chamber in collaboration with the Texas Center for Superconductivity, headed by former SVEC director Dr. Paul W. Chu.

Breaking New Ground

The accomplishments of CCDS participants include profound advances in a number of scientific fields and hundreds of Earth and space-based applications.

The 1986 superconductivity breakthrough by two scientists associated with NASA's CCDS program and a subsequent breakthrough by one of the same scientists, Nobel Prize nominee Dr. Paul W. Chu, of the Space Vacuum Epitaxy Center, University of Houston, received worldwide attention and marked historic scientific achievements which promise significant social and economic implications.

Pioneering research into the use of space for the production of superior quality protein crystals is being performed under the leadership of the Center for Macromolecular

Crystallography (CMC), University of Alabama Birmingham.

Under this effort, major U.S. pharmaceutical companies — industrial affiliates of the CMC — are providing samples for space-based protein crystal growth. Acquiring high quality crystals from space could significantly advance research leading to the development of new drug treatments.

CMC experiments have flown on several space shuttle flights, including the post-Challenger missions of STS-26 and STS-29.

In 1989, another CCDS, The Consortium for Materials Development in Space (CMDS), University of Alabama, Huntsville, and affiliates [illegible] materials processing research [illegible] the first commercial [illegible] rocket launch.

Space Services Inc., [illegible]-based firm [illegible] competitive commercial launch services [illegible] CMDS for the March 1989 launch of a materials science experiment payload aboard the firm's Starfire rocket.

Starfire's successful launch not only advanced research in materials processing, but also helped further federal efforts to foster growth of a strong and vigorous U.S. commercial launch industry.

Other collective CCDS accomplishments include drop tube experiments, KC-135 flight experiments, Lear jet flights, and participation on Space Shuttle flights.

Program Structure

NASA's Office of Commercial Programs (OCP) selects, manages, and provides annual funding of up to $1 million to the centers [illegible] leveraging of NASA grant investments and increasing reliance on industrial sponsorship.

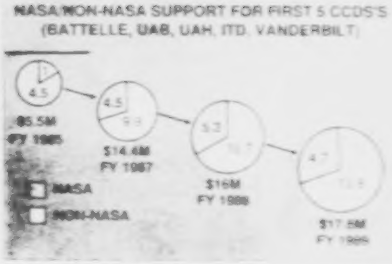
The centers receive additional financial and in-kind contributions from industrial affiliates, which on the average exceed the NASA funding level. In 1986, less than one-fifth of the total funding for the first five CCDSs was derived from non-NASA sources. By 1988, non-NASA funding comprised nearly three-fourths of the total funding for the five centers.

NASA also provides the centers with scientific and technical expertise, opportunities for cooperative activities, and other forms of continuing assistance.

Since initiation of the program, OCP's Commercial Development Division has issued three proposal solicitations inviting [illegible] areas of promising space-based commercial R&D.

From the solicitations, 16 centers have been established in seven major research areas. These areas include five CCDSs

Starfire 1, the first U.S. rocket licensed for commercial spaceflight, burst off Launch Complex 36 at White Sands Missile Range, New Mexico, at 8:48 a.m. MST, March 29, 1989, ushering in a new era of commercial rocket launches and evidencing how NASA funding, university talent, and industry ingenuity can combine to spawn new commercial enterprises.



This chart shows the percentage of the total funding for the first five Centers for the Commercial Development of Space derived from NASA and non-NASA sources from 1986–89.

Astronaut George "Pinky" Nelson activated and monitored the protein crystal experiments, sponsored by NASA and the Center for Macromolecular Crystallography, aboard Discovery on STS-26 in September 1988.

dedicated to materials processing research, three conducting life science-related research, two in remote sensing, two committed to automation and robotics, one concentrating on space propulsion, one devoted to space structures and materials, and two focusing on space power research.

The centers are based at universities and research institutions across the country and are linked with at least one NASA field center.

Future Focus

As an incubator for future commercial space industries, the CCDS program has facilitated a number of new commercial space ventures since its inception and supported a wide range of on-going efforts. In the future, it is anticipated that each center will lead to new Joint Endeavor Agreements between NASA and industry. These no-exchange-of-funds agreements are designed to encourage early space ventures and demonstrate the use of space technology to meet marketplace needs.

In addition, development of a new agreement mechanism to facilitate early space flight opportunities for CCDS participants is being finalized.

To date, some 40 Space Shuttle flight request forms have been submitted to OCP by the centers.

To accommodate the growing demand for CCDS-sponsored secondary Space Shuttle payloads, a CCDS payload selection/ranking process has been developed by OCP.

Emphasis will also be placed on providing industry with other forms of opportunities for commercial space research, such as the CMDS-sponsored sounding rocket launch which was the first in a series of such launches planned.

The second of such launches will carry experiments sponsored by a number of CCDSs and is planned for the fall of 1989.

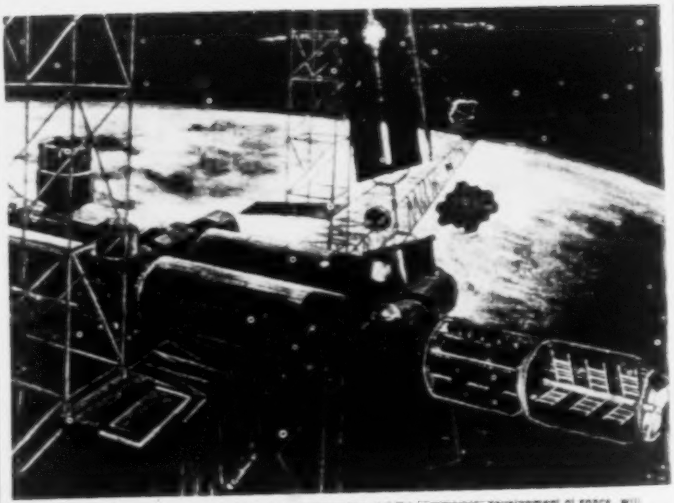
Efforts to ensure greater CCDS involvement in current and future commercial space activities will continue. A Management Working Group, comprising center directors, has been formed to provide NASA officials with increased CCDS input on commercial program activities.

An initiative is also underway to ensure strong CCDS involvement in the commercial aspects of the Space Station Freedom program. A team of members from each center will be formed to serve as designated CCDS Space Station planners and spokesmen.

The CCDS program has emerged as a critical tool toward increasing industry involvement in U.S. commercial space activities, encouraging and supporting new and ongoing commercial space ventures, as well as spawning research and development advancements which promise enormous social and economic benefits for all. This booklet was prepared by the Office of Commercial Programs to provide an introduction to each of these unique centers and their activities.

For more information on NASA's CCDS program write:

CCDS Program Manager
NASA Headquarters
Commercial Development Division (Code [illegible])
Washington, DC 20546



The Space Station Freedom, the next step in space exploration and the commercial development of space, will involve the participation and input of NASA's 16 Centers for the Commercial Development of Space (CCDS). The Wisconsin Center for Space Automation and Robotics (WCSAR) represents just one of the CCDSs working to develop technologies that will contribute to the success of the Space Station and future space goals. WCSAR's efforts to develop automated plant growth facilities for space are illustrated in an artist's concept of a plant growth unit attached to the Space Station.

Advanced Materials Center for the Commercial Development of Space

Formed in November 1985, the Advanced Materials Center for the Commercial Development of Space, located at Battelle Memorial Institute in Columbus, Ohio, conducts research into advanced materials including polymers, catalysts, electronic materials, metals, ceramics, and superconductors.

Commercial applications of these materials are selected for study in microgravity, with the objective of improving the characteristics of the commercial product, improving the process by which the product is made, or gaining additional information about the material, which could improve Earth-based processing. All programs selected for study are defined by industry partners.

Participants in the Battelle CCDS are supported by Lewis Research Center and Marshall Space Flight Center. Both contribute facilities, expertise, and flight development consultation. Center membership includes the following companies from the private sector:

- Amoco Chemical Company
- DuPont
- Hercules
- Master Builders, Inc.
- Rockwell International
- Teledyne Brown Engineering
- II-VI, Inc.

Other companies contributing to the center's operations are General Electric, Lockheed, and PPG, Inc.

University affiliates are engaged on a subcontracted basis to perform key aspects of the center's research activities. Affiliate members include the following:

- Akron University
- Case Western Reserve University
- Clarkson University
- Cleveland State University
- Ohio State University
- Washington State University
- Worcester Polytechnic Institute

The center is currently working in four major technology areas. These include catalysis, polymers, semiconductors, and rapid solidification of metals and ceramics, including superconductors.

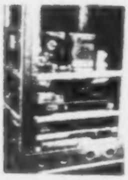
In both the catalyst and polymer areas, a significant amount of the ground-based research has been completed and numerous short-time microgravity tests have been conducted. Current efforts are centered on preparing for space flight by developing hardware and modifying existing NASA hardware. Several flights aboard the Space Shuttle and in sounding rockets are planned beginning in 1989.

The center's semiconductor research is focused on the high-temperature crystal growth, by the float-zone method, of CdTe. While the pre-flight work is lengthy and difficult, this program is considered by industrial partners to be extremely important commercially.

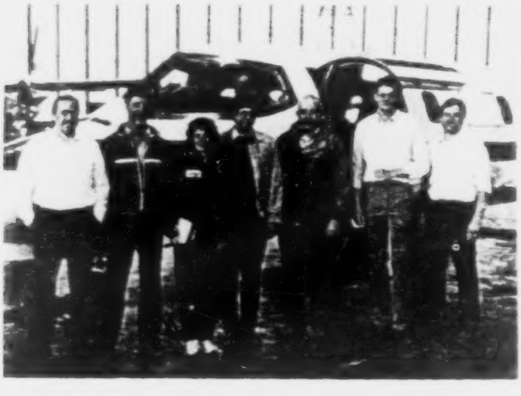
The opportunity for deep undercooling and containerless processing that the microgravity environment provides is ideally suited for solidification studies. In this fourth research area, work is underway on ceramic superconductors, liquid phase immiscibles, and bearing materials.

Further information on the Advanced Materials CCDS can be obtained by writing:

Mr. Frank J. Jelinek
Director
Advanced Materials CCDS
Battelle
505 King Avenue
Columbus, OH 43201-2693
(614) 424-6376



This apparatus was flown on the Lear jet to produce the polymer composites.



The flight and science crew of a Battelle center project to produce polymeric composites in low gravity stand in front of the Lewis Research Center Lear jet used to fly the experiments.

Center for Space Processing

An Ultra-high Temperature, Directional Solidification Furnace is used by the center in its exploration of the space processing of engineering materials

In the unique microgravity environment of space, an almost limitless potential for significant advancements in Earth- and space-based materials processing exists. These promises of profound advances — ranging from creation of stronger metals to unique new materials — are being explored by the Vanderbilt Center for the Space Processing of Engineering Materials.

Established in 1985, the center is located on the Vanderbilt University campus in Nashville, Tennessee. Major research involves microgravity experimentation in containerless processing, directional solidification casting, and cold welding. Studies are being conducted on four materials: metals, alloys, ceramics, and glasses.

By creating the methodology and technology needed to simulate processing of these four materials in a space environment, the Vanderbilt Center's efforts have greatly increased the scope of microgravity research.

The results of these efforts will be seen in the application of research to Earth-based manufacturing processes and will provide the basis for future commercial exploration of the space environment and resources.

Current center projects include: Directional Solidification of Aluminum Casting and Wrought Alloys, Deep Undercooling of Nickel and Iron Aluminides, Containerless Processing of Iridium and Ruthenium, Casting and Directional Solidification of Immiscible Alloy Systems, Containerless Processing of Refractory Alloys, and Solidification of Niobium Titanium Alloys.

Each of these projects has a direct commercial connection to the manufacture of metals and materials with attributes for high performance such as enhanced corrosion resistant properties, wear resistant properties, high temperature strength, oxidation and resistance.

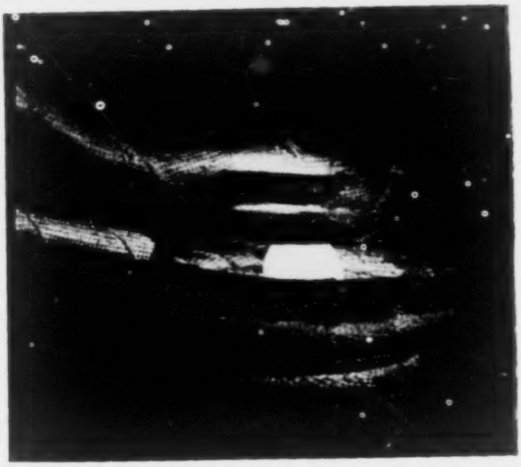
Another unique project has been the design of a 50-meter drop tube to expand the center's facilities for simulating a microgravity environment for future experimentation. Funds have been pledged by NASA, corporate center members and Vanderbilt University to undertake the construction of this drop tube.

Experimentation has been conducted at Marshall Space Flight Center, Lewis Research Center and Oak Ridge National Laboratories. The center also works with subcontractors at the University of Florida, Gainesville, the University of Alabama, Tuscaloosa, and with industrial partners at Engelhard, GTE, Lockheed, Boeing, Teledyne Brown, Teledyne Wah Chang, and the Cabot Corporation.

Based on the success of current microgravity projects, the Vanderbilt Center for Space Processing will continue to provide the American space program with the kind of profitable and practical results needed to fully involve corporate America in future space efforts. This partnership among industry, universities and NASA can contribute to U.S. technological leadership and economic prosperity as the frontier of space is developed.

For more information on the CCDS contact:

Center for Space Processing
Program Coordinator
P.O. Box 6309
Station B
Nashville, TN 37235
(615) 322-7047



A levitation-melted copper sample is shown

Consortium for Materials Development in Space

The Consortium for Materials Development in Space, established at the University of Alabama in Huntsville (UAH) in 1985, focuses on investigations in space as a means to develop new materials and processes.

This approach covers commercial materials development that benefits from the unique attributes of space, commercial applications of the physical chemistry that occurs at the surface of a new material, and how materials are transported in it, and prompt and frequent experiments and observations in space.

Current industrial partners are Boeing Aerospace, Deere & Company, Fountain Research, IBM's Almaden Research Center, McDonnell Douglas, Teledyne Brown Engineering, and Wyle Laboratories.

CMDS's prime NASA partner is Marshall Space Flight Center, although other NASA centers are strong supporters. UAH participates in the CMDS through its Schools of Science and Engineering and four university research centers.

The principal activities of the consortium are organized into several projects, each with at least one co-investigator from industry and a special university investigation team.

CMDS's most significant science accomplishment to date is a 1986 breakthrough in high-temperature superconductors. CMDS was a principal source of funding and talent for the development of the first materials that conduct electricity without resistance at temperatures higher than liquid nitrogen, 77K (-321°F).

The mixed-phase metal oxide developed by scientists at UAH remains superconducting at 93K (-292°F) and spurred a global race to develop and manufacture devices based on these materials.

Several CMDS projects emphasize the development of materials with highly nonlinear optical characteristics. These take the form of organic thin films, gases, crystals or fibers, which one day may be applied to computers that use light instead of electrons.

Surface coatings for a variety of applications constitute another line of materials development. Atomic oxygen can erode coatings that must maintain constant properties on spacecraft surfaces for extended periods.

Understanding materials produced by electrodeposition is another area addressed by the CMDS in a project sponsored by McDonnell Douglas. Several polymer projects — such as gravitational effects on demixing of polymers, formation of foams in microgravity, and improved materials for radiation detectors — are included in the CMDS program. Powdered metal sintering and mineral processes under microgravity conditions are further subjects of development.

Research has been carried out on the ground and aboard NASA's KC-135 low-gravity aircraft as preparation for space flight aboard suborbital rocket and orbiting carriers.

In 1987, CMDS began working toward a sounding rocket flight. UAH selected Space Services Inc. to provide a launch in March 1989 aboard a Starfire I launch vehicle. That successful endeavor was the first U.S. commercial licensed launch and signified the beginning of a new era in U.S. commercial launches.

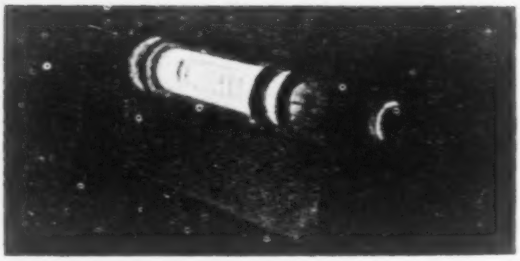
The Consort I flight carried six experiments for a seven-minute period of microgravity.

Future CMDS flight experiments will be aboard suborbital rockets, carriers on Spacelab, and the U.S. Microgravity Laboratory.

For more information on the Consortium for Materials Development in Space contact:

Dr. Charles Lundquist
Consortium for Materials Development in Space
University of Alabama in Huntsville
Huntsville, AL 35899
(205) 895-6620

Liquid nitrogen bubbling in a plastic cup demonstrates how "hot" superconductivity has become following a development by Marshall Space Flight Center and the Consortium for Materials Development in Space (CMDS) officials. The mixed-phase metal oxide retains its strong magnetic field at -160 C. The suspension effect shown here, caused by a magnetic field trapped in the sample, was discovered by CMDS and Marshall officials when silver oxide was added to the CMDS recipe for superconductors.



A prototype of a physical vapor transport furnace supplied to the center by Boeing for ground-based testing is illuminated by the glow from its own heat.

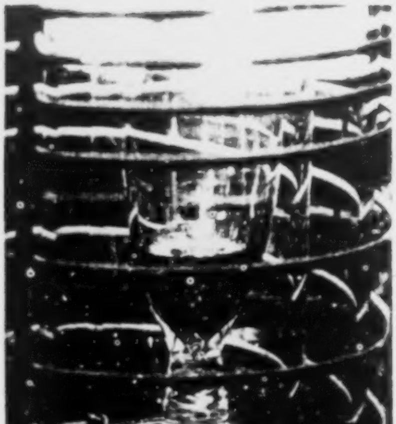
Materials Processing

Center for Commercial Crystal Growth in Space

This doped triglycine sulfate crystal was grown in 1 g.

Clarkson University's Center for Commercial Crystal Growth was established in September 1986. This national consortium of industry, universities and national laboratories is based at Clarkson University, Potsdam, New York.

The center's primary goal is development of commercial crystal growth in space, with emphasis on growth of single crystals of higher perfection than can be grown on Earth. Applications of this venture include electronics, optical systems, detectors, and separations.



The transparent furnace shown was developed by Boeing to enable scientists to view crystals during growth in space.

Primary corporate sponsors of the consortium are Boeing Aerospace Corporation, Grumman Corporation, EDO/Barnes Engineering, and the Westinghouse R&D Center. A host of other companies, both small and large, contribute to center activities.

University researchers include Alabama A&M University, the University of Florida at Gainesville, the National Institute of Standards and Technology, Rensselaer Polytechnic Institute and Worcester Polytechnic Institute. Marshall Space Flight Center also provides assistance to the center.

Research is performed by three teams: Melt Growth, Vapor Growth, and Solution Growth. The National Institute of Standards and Technology (NIST) participates in each of these teams. NIST utilizes the National Synchrotron Light Source at Brookhaven National Laboratories to characterize crystals by high resolution X-ray topography.

Primary participants in the Melt Growth Team are Clarkson University, the University of Florida, Grumman, and the II-VI Corporation. This team is working on growth of cadmium telluride crystals by the Bridgman-Stockbarger technique and growth of gallium arsenide crystals by the liquid encapsulated molten zone technique.

These crystals are used in producing more resilient integrated circuits and infrared detectors. Potential applications include faster computers and more detailed infrared images.

Vapor Growth Team participants include Rensselaer Polytechnic Institute, Boeing, and Westinghouse. The Vapor Growth team is working on growth of cadmium telluride and mercury halide crystals by vapor transport techniques. Potential applications include devices for detecting high-energy particles such as nuclear radiation and cosmic rays.

Participants in the Solution Growth Team are Alabama A&M University, Worcester Polytechnic Institute, and Barnes Engineering. The Solution Growth Team is working on crystal growth of triglycine sulfate, L-alanine phosphate and zeolites.

Potential applications include optical computers, devices used to change the frequency or "color" of laser light, room temperature infrared detectors, catalysts for the petrochemical industry, and separation of chemicals produced by biotechnology and radiation waste storage.

Each of the above teams is performing ground-based experiments and planning flight experiments.

While the ground-based work is aimed primarily at preparing for flight experiments, it is producing results useful now for commercial crystal growth on Earth.

For more information on the Center for Commercial Crystal Growth in Space contact:

Bill Wilcox
Center for Commercial Crystal Growth in Space
Clarkson University
Potsdam, NY 13676
(315) 268-[illegible]

Space Vacuum Epitaxy Center

The Space Vacuum Epitaxy Center (SVEC) — a major research consortium based at the University of Houston — is developing new techniques to use the ultra-vacuum of space for materials processing.

Established by NASA in 1986, this Center for the Commercial Development of Space is located in the Houston Science Center complex.

Research facilities include an Epitaxial Thin Film Facility with Class 10, Class 1000, and Class 10,000 clean rooms, Thin Film Superconductor Laboratory, and Analysis Laboratory.

Center participants include AT&T Bell Labs, Murray Hill, New Jersey; Electro-Optek, Torrance, California; Instruments S.A., Inc., Edison, New Jersey; Perkin-Elmer, Eden Prairie, Minnesota; Rockwell International, Thousand Oaks, California; U.S. Army Research Division, Watertown, Massachusetts; University of Illinois, Urbana, Illinois.

NASA field centers assisting SVEC include Johnson Space Center, Houston, Texas, and Marshall Space Flight Center, Huntsville, Alabama.

The Center's primary research focus is aimed at exploring epitaxial thin film growth and materials purification in the ultra-vacuum of space.

An ultra-high vacuum allows for the controlled deposition of unique thin films by epitaxial growth. Researchers consider vacuum epitaxy to be the most powerful technique available for synthesizing new thin film electronic, superconducting and magnetic materials and devices.

Unique epitaxial procedures developed at SVEC can be used for production of these new products, which possess enhanced qualities.

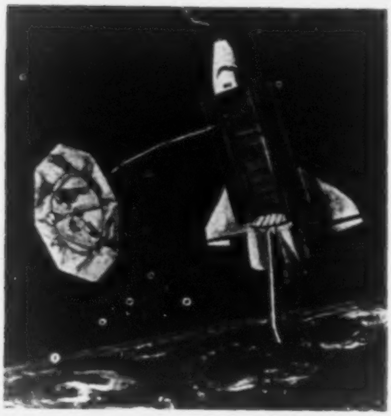
In addition to providing an excellent environment for epitaxial thin film growth, space allows for the purification of materials needed in the production of high-quality semiconductor, superconductor, and magnetic materials.

SVEC's future efforts will concentrate on adapting Molecular Beam Epitaxy and Chemical Beam Epitaxy (MBE and CBE) technologies to the space ultra-vacuum environment and development of semiconductor thin film materials and devices.

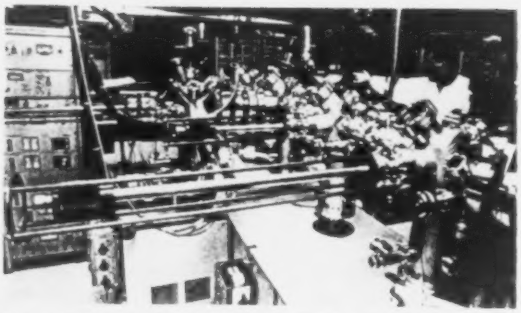
A major emphasis is also being placed on helping to increase access to and utilization of the space ultra-vacuum. The ultra-vacuum can be achieved by deployment of a Wake Shield Facility (WSF) in a low Earth orbit. SVEC and Space Industries, Inc., of Houston, are jointly developing the flight hardware for a Shuttle-deployable WSF. Researchers expect the disk-shaped wake shield to produce an ultra-vacuum in the order of 10^{-14} torr in its wake.

For more information on this CCDS contact:

Space Vacuum Epitaxy Center
Attn: Dr. Alex Ignatiev
Director
University of Houston
Houston, TX 77204-[illegible]
(713) 743-[illegible]



Operating a wake shield in space can create a higher quality environment for the production of thin film materials than anything achievable on Earth. Deployed by the Space Transportation System in a low Earth orbit, the shield pushes aside stray atoms and molecules to create an ultra-vacuum in its wake.



The Space Vacuum Epitaxy Center houses a unique Molecular Beam/Chemical Beam Epitaxy System for thin film semiconductor growth, which is shown being operated by a research scientist.

Life Sciences

Center for Macromolecular Crystallography

Protein crystal growth experiments sponsored by NASA and the Center for Macromolecular Crystallography were flown on STS-26. The experiments included a sample of the enzyme isocitrate lyase for fungicides — a crystal of which is shown. Better understanding of this enzyme could lead to more potent fungicides to treat serious crop diseases such as rice blast.

The Center for Macromolecular Crystallography (CMC), a unit of the University of Alabama at Birmingham, Alabama, was among the first five of NASA's Centers for Commercial Development of Space established in 1985.

The center's research programs cover all major areas of macromolecular crystallography. Crystallography is the only technique available for determining the three-dimensional atomic arrangements within complicated biological macromolecules. By bombarding crystals of a macromolecule with X-rays, diffraction patterns are produced that permit determination of the molecule's complete architecture. The resulting structural information is essential for understanding the fundamental structure/function relationships that regulate biological systems.

Macromolecular crystallography is a powerful research tool in the pharmaceutical, chemical, and biotechnology industries for drug design and protein engineering. Recent results from Space Shuttle experiments demonstrate that improved crystals of biological macromolecules can be obtained using the unique microgravity environment of space.

The center is involved in development of new techniques for protein crystal growth on Earth and in space, structural studies of biological macromolecules using protein crystallography, applications of protein crystallography in drug design and protein engineering, and development of improved hardware and software systems for assisting in various experimental aspects of macromolecular crystallography.

CMC facilities and personnel are available to industrial guest investigators, which currently include scientists from BioCryst, Burroughs-Wellcome, Dow, Dupont, Eli Lilly, Genentech, Eastman Kodak, Merck, Procter & Gamble, Schering-Plough, Smith Kline-Beckman, and Upjohn. In addition, the center has collaborative microgravity research programs with other universities and government laboratories, including the Marshall Space Flight Center, University of Alabama in Huntsville, University of North Carolina, University of Texas, University of Pennsylvania, Brookhaven National Laboratory, University of Washington, University of Chicago, Georgia Institute of Technology, and the Naval Research Laboratory.

CMC-sponsored protein crystal growth experiments flew on the first post-Challenger mission of STS-26 in the fall of 1988, and an additional set of experiments was flown on STS-29 in early 1989.

Recent major achievements of the center include determination of the three-dimensional structure of human purine nucleoside phosphorylase, an enzyme that is a target for the design of drugs to be used in cancer and AIDS chemotherapy, suppression of the immune system in tissue transplants, and for treatment of autoimmune diseases such as rheumatoid arthritis. The structural results for this protein have already led to the development of several potent new inhibitors of the enzyme. Results from the protein crystal growth experiments on STS-26 and STS-29 provided clear evidence that microgravity can be used effectively to produce improved protein crystals for structural studies. Advanced hardware now being developed through the center will allow industrial guest investigators to be involved in forefront applications of microgravity to protein crystal growth on future Shuttle flights and ultimately on the Space Station. □

For further information on the Center for Macromolecular Crystallography, contact:

Dr. Charles Bugg
Center for Macromolecular Crystallography
University of AL, Birmingham
THT-Box 79, University Station
Birmingham, AL 35294
(205) 934-5329

Dr. Thomas Krenitsky of Burroughs Wellcome, an industrial affiliate of the Center for Macromolecular Crystallography (CMC), purifies a potential inhibitor of the protein reverse transcriptase. Burroughs Wellcome provided a sample of the protein — a proven target for AIDS drug development — as part of the NASA/CMC-sponsored protein crystal growth experiment package flown on STS-26.

Bioserve Space Technologies

Bioserve Space Technologies, a center for the Commercial Development of Space, was established at the University of Colorado, Boulder, Colorado in October 1987 [illegible] foundations, government and academic [illegible]. Bioserve [illegible] research.

[illegible]

[illegible] University of Colorado [illegible]

[illegible]

1. [illegible]

[illegible]

Recently, Bioserve performed pioneering experiments on one of NASA's KC-135 microgravity research aircraft.

2. [illegible]

[illegible] environments of space.

[illegible]

3. [illegible]

[illegible]

[illegible] waste management, and agricultural [illegible]

[illegible]

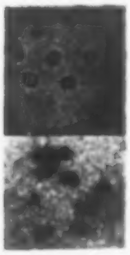
4. [illegible]

[illegible]

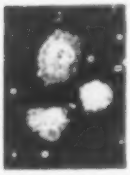
Payload systems executive and former astronaut Byron Lichtenberg jokes on as University of Colorado student researchers and NASA astronaut Marsha Ivins ham it up for the camera at the conclusion of a three-day series of microgravity KC-135 flights.

Life Sciences

Center for Cell Research



Growth hormone secretion from individual pituitary gland cells can be examined clearly through the use of the cell blot technique.



The orange-colored blots shown above illustrate acid production by cultured osteoclasts, the cellular agents of bone resorption.

The Center for Cell Research (CCR), established in 1987, is a biologically oriented CCDS. Its main goals are definition of the fundamental mechanisms of mammalian cell function on Earth and in space and commercialization of the findings in cooperation with business and industry.

The CCR is a national science center based at Pennsylvania State University (PSU). The current roster of 32 scientists come from the colleges of Science, Chemical Engineering, Agriculture, and Health and Human Development at PSU, Arizona State University, Columbia University, Jefferson Medical College, Mayo Clinic, Nemours Foundation, Tulane University, UCLA, University of Wisconsin, as well as from the Ames Research Center and Johnson Space Center.

These scientists (who specialize in cell secretion, differentiation, energetics, biochemistry and proliferation; biomechanics, shear effects; and cell and molecular separations) were selected because of contributions they can make to the three major projects of the center — the musculoskeletal system (bone and hematopoiesis), the light/endocrine/immune axis, and bioprocessing. A state-of-the-art core cell analysis and separation facility supports their efforts (Fig. 1).

This basic research relates to commercial concerns — aging, anemia, bioprocessing, cell secretion, diabetes, drug delivery, hormone production, immune function, light effects, muscle atrophy, osteoporosis, transfected cells, etc.

For example, Lunar Radiation Corporation, Wisconsin, is attempting to miniaturize its dual-energy bone densitometer in order to monitor bone density of personnel and animals in space and on earth. Corabi International Telemetrics, Maryland, is marketing a telepathology instrument for long distance transmission and control of microscope images and developing it for use on Freedom Space Station. Genentech, California, has contracted with the CCR to perform animal experiments in microgravity.

The CCR will assist them by (1) participating in the R&D, (2) doing ground-based testing, (3) making it possible for them to test in space, and (4) fostering collaboration between them and other CCR-affiliated companies.

Other client projects relate to several aspects of bioprocessing in space, microgravity-caused aberrations in mammals which resemble diseases on Earth, and visible light-caused changes in immune response.

For more information on the Center for Cell Research contact:

Dr. Sylvia Stein
Executive Director
416 Wartik Laboratory
Penn State University
University Park, PA 16802
(814) 865-2416

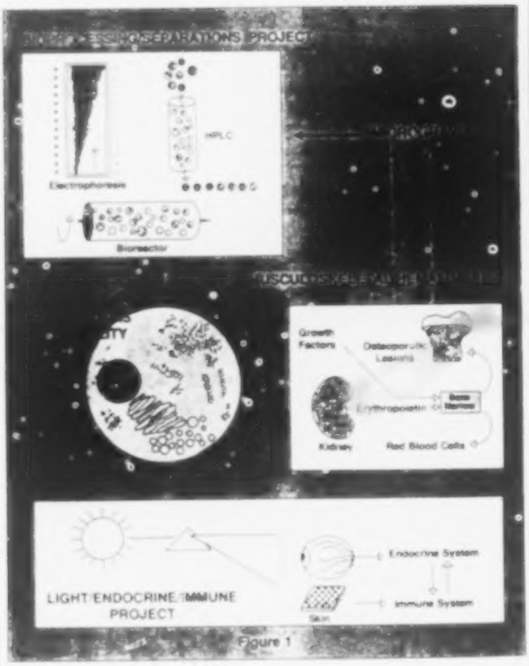


Figure 1

Center for Mapping

The NASA sponsored Center for the Commercial Development of Space (CCDS): Real-Time Satellite Mapping at The Ohio State University was funded in 1986 and is a part of the Center for Mapping. This center aims to develop methods of gathering information from satellites, correlating that information with existing data, and applying advanced mapping techniques in the commercial market place in "real time."

Center industrial partners include Battelle Memorial Institute, Corrugated Plastic Tubing Association, Digital Equipment Corporation, Earth Satellite Corporation, Gas Research Institute, Intergraph, Environmental Systems Research Institute, The Nature Conservancy, Ohio Department of Natural Resources, Synercom Technology, Inc., Tektronix, Inc., Trimble Navigation, Ltd.

Corporate/government affiliates include Agriculture Research Service, American President Lines, Coastal Science & Engineering, Inc., Conservation Technology Information Center, ERDAS, Inc., GeoSpectra, Inc., Goddard Space Flight Center, Intergraph Corporation, John Hopkins Applied Physics Laboratory, Metropolitan Parks Commission of Columbus & Franklin County, Micronautics, Inc., Mid-Ohio Regional Planning Commission, Muskingum Watershed Conservancy, National Ocean Service/NOAA, Ohio Chapter of Land Improvement Contractors of America, Stilson Associates, USDA-ARS Beltsville Agricultural Center, USDA-ARS Soil Drainage Research Unit, USDOT Maritime Administration, and U.S. Geological Survey.

The research and demonstration projects conducted at the CCDS are primarily driven by commercial needs in land, water and farm management, in energy and power production, digital mapping, information systems, and disaster assessment. Consequently, research efforts have ranged from forecasting storm surge levels to analyzing the impact of drought conditions in the Midwest, from anticipating satellite orbits to monitoring gas leaks, and from predicting the effects of erosion to tracking ocean currents.

Two of the center's most successful projects are "Feature Extraction From Aerial Photographs and Interpreting Raster Scanned Map Data" and "Extracting Three-Dimensional Information from Aerial Imagery and Determining Elevation Models." These projects seek to provide an automatic means of tapping a rich source of information, namely maps. In these projects "expert systems" or artificial intelligence techniques are used to solve difficult problems in automated map interpretation and image analysis. The overall goal of these two projects is to produce and update maps from satellite and aerial imagery faster and more reliably.

Because of the groundbreaking nature of the research and the unique utilization of photogrammetry and computer vision, two companies, Digital Equipment Corporation (DEC) and Intergraph Corporation, became interested in the project.

With the new technology and expertise brought to the project by DEC and Intergraph, future research efforts will focus on the construction, refinement, and augmentation of object space descriptions from satellite and aerial stereo image pairs (the so-called "feature extraction from both image and object space descriptions").

For further information on the Center for Mapping contact:

Center for Mapping
The Ohio State University
1958 Neil Avenue
Columbus, OH 43210-1247
(614) 292-6042

The Big Darby Creek Watershed area shown in this photo is the focus of one of the center's major research projects.

This computer-generated soil classification map shows the varying compositions found in soil near the Big Darby Creek Watershed and illustrates how technology being developed by the center can be used to provide wide range of information.

Remote Sensing

Space Remote Sensing Center

The Space Remote Sensing Center develops specific applications of remote sensing for diverse problems that can be solved through the use of this technology.

The Space Remote Sensing Center (SRSC) is developing commercial applications of satellite and airborne remote sensing, image processing, and geographic information systems. As a division of the Institute for Technology Development, the SRSC has established a close relationship with numerous universities, private organizations and NASA's Science and Technology Laboratory, located at the Stennis Space Center. Through these associations, SRSC is finding ways to improve the operational productivity and efficiency of those involved in land use planning and resource management.

The applications development program at SRSC is creating advanced techniques for agriculture, crop monitoring, forest management, environmental assessment, facilities monitoring and land use planning. Economic benefits are gained directly from improved operational planning, which can lead to lower product costs.

In agriculture, SRSC is developing image processing techniques and computer models to assess crops and yield for several crops. Diverse commercial interests including Hewlett Packard Company, agricultural banks, Mississippi Agricultural Center, Mississippi State University and Purdue University have resulted in several applications with commercial success. One such is a crop consulting tool derived from remotely sensed data. Farmers can use this tool to reduce fertilizer cost by limiting each soil unit according to the soil's potential to grow a crop. Montana farmers working with this technology have saved between $7 and $11 per acre.

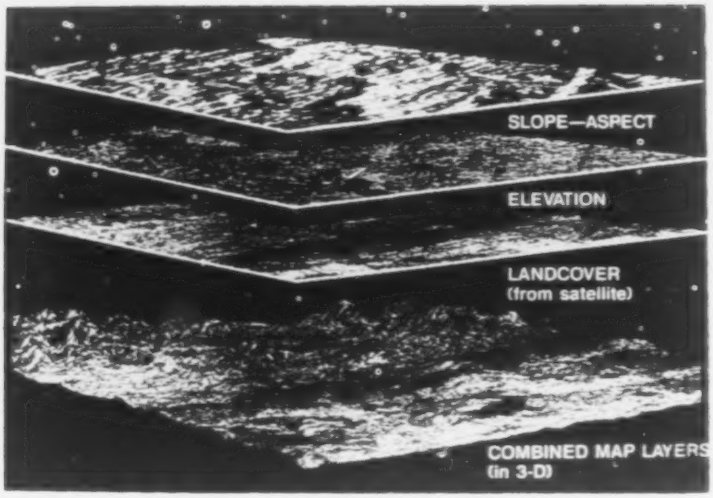
The forestry industry has also benefited from projects that SRSC has conducted involving large land owning companies in assessing the commercial application of remote sensing for forest management.

SRSC has been designated as the official support center for the U.S. Army Corps of Engineers Construction Engineering Research Laboratory's software package called GRASS (geographic resources analysis support system). The geographic information and image processing system has been recently ported to the Apple Macintosh II™ personal computer through SRSC's Apple Developer partnership. This has enabled many potential users of remote sensing and geographic information to access this data on a low cost system.

Through these efforts, SRSC will continue to explore and develop applications of remote sensing to benefit the private sector.

For more information on the Space Remote Sensing Center contact:

Director
ITD Space Remote
Sensing Center
Building 1103, Suite 118
Stennis Space Center, MS
39529
(601) 688-2509



Creating a database with multiple data layers is important in managing commercial applications of remote sensing technology. This geographic information system image display shows how data layers can be combined to produce three-dimensional perspective views containing information from each layer.

Wisconsin Center for Space Automation and Robotics

Automation and robotic technologies will be essential to the success of planned future space missions. To meet technology needs in this area, advanced capabilities, far beyond those currently available, will be required.

The Wisconsin Center for Space Automation and Robotics (WCSAR) is working to meet this challenge. Established at the University of Wisconsin-Madison in September 1986, WCSAR's research in this innovative field is expected to produce a wide range of terrestrial spin-off applications.

The center's three major research areas include Astrobotics™, Astroculture™ and Astrofuel™.

In Astrobotics™, WCSAR is working to create robotic technologies capable of enhancing mankind's ability to live, travel, and explore in space. Robotic technology will be especially useful for accomplishing tasks in hazardous environments and those areas not easily accessible to humans. As an extension of the astronaut, this technology will be used to assist in performing a variety of complicated and routine tasks outside the spacecraft.

In Astroculture™, WCSAR is working to develop automated plant growth facilities for space. These galactic gardens will provide a plentiful source of oxygen and food, remove carbon dioxide, and purify water for long-duration and permanently manned space operations. In addition, plants will enhance the aesthetic quality of life in a space colony.

Astrofuel™ involves the mining and processing of Helium-3, an extremely valuable source of safe, clean, reliable fusion fuel. Identified as a component of the lunar regolith, the amount of Helium-3 on the Moon is estimated to be the energy equivalent of ten times that of the Earth's remaining fossil fuels. Successful recovery and transport of Helium-3 back to Earth may solve our energy needs for centuries to come.

WCSAR conducts research in laboratory facilities throughout the University of Wisconsin-Madison campus. Talent is drawn from university faculty and staff in engineering, agriculture, medicine, and the physical sciences, together with industrial consortium members.

The Lyndon B. Johnson Space Center serves as WCSAR's main NASA field center. Other NASA field centers, including Kennedy Space Center, Ames Research Center, Lewis Research Center, and Goddard Space Flight Center are also involved in cooperative activities with the WCSAR program.

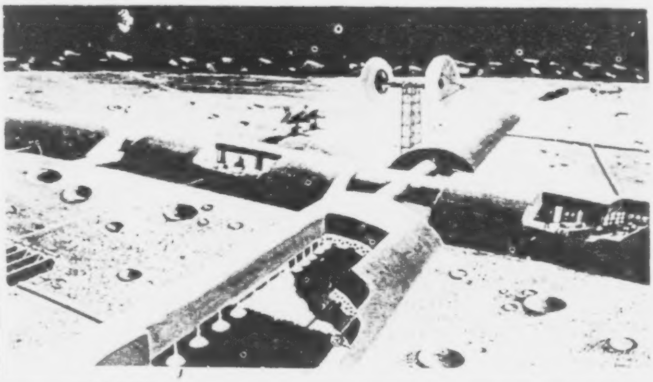
WCSAR's industrial participants are Astronautics Corporation of America, Automated Agriculture, Inc., Deere & Co., McDonnell Douglas Astronautics Corporation, Orbitec, Orbital Technologies Corp., PhytoFarms of America, Pierson Products, Inc., Silicon Sensors, Snap-On Tools Corporation, Sundstrand Corporation, Sevrain Tech, Inc. and the State of Wisconsin Department of Development.

University participants are University of Wisconsin-Madison, University of Wisconsin-Milwaukee, Milwaukee School of Engineering, and Marquette University.

For more information on the Wisconsin Center for Space Automation and Robotics contact:

Heidi Wilde
Program Coordinator,
Wisconsin Center for Space
Automation and Robotics
1357 University Avenue
Madison, WI 53715
(608) 262-5524

An artist's rendition is shown of a maneuvering anthropomorphic system functioning in both the autonomous and teleautonomous mode of a space station operation.



This conceptual illustration depicts a plant growth unit as a component of a lunar base.

Automation and Robotics

The Center for Autonomous And Man-Controlled Robotic and Sensing Systems

Investigations concerning the use of plant cell cultures as a resource for space exploration are aimed at developing Controlled Ecological Life-Support Systems for long-term space missions and extraterrestrial bases.

In April 1987, a team of leading academic, research, and private-sector institutions formed a consortium under NASA sponsorship to demonstrate the feasibility of commercial autonomous and tele-autonomous services in space. The Center for Autonomous and Man-Controlled Robotic and Sensing Systems (CAMRSS) promotes synergy among its participants and serves as a liaison between NASA, academia, and private industry.

Among the key technologies CAMRSS is developing to make space industrialization possible are machine vision and sensing systems, robotics and automated manufacturing systems, and biological technology for life support systems.

CAMRSS is located in Ann Arbor, Michigan, a fast-growing high-technology community with over 100 industrial research firms and government laboratories, and is housed at the Environmental Research Institute of Michigan (ERIM).

CAMRSS's research program supports existing CCDS activities in space-based materials processing and is coordinated with NASA's Space Station activities.

Current members include:

Ball Aerospace
Coulter Electronics
Environmental Research
 Institute of Michigan
Fairchild Space Company
Ford Aerospace
Geospectra Corporation
Grumman Corporation
Industrial Technology
 Institute
KMS Fusion, Inc.
Michigan State University
Michigan Strategic Fund
The University of Michigan

The center's two main research areas constitute missing links to long-term commercial space development. The first is automated construction, repair and maintenance of orbital and remote planetary systems. Before space industrialization can become a reality, methods of maintaining the operational elements of remote systems must be determined.

The second activity concentrates on space-based biomass production, including biological systems for long-duration life support and automated biological processing.

CAMRSS's work requires developing tele-autonomous robots which are independent enough to function in variety of situations, yet are responsive to remote communication from a human operator. To support biomass production in space, new automation concepts in laboratory and life support systems design must also be explored.

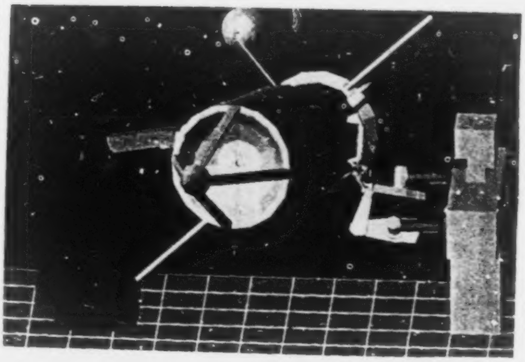
Another facet of CAMRSS's research effort is to define the market and marketing strategy for space servicing technology. To help ensure near-term profitability, each of the center's projects is linked to a clearly demonstrated terrestrial market.

CAMRSS also offers expertise to small businesses pursuing external funding opportunities. In Michigan, one half of the most recent Small Business Innovation Research (SBIR) program recipients were supported by CAMRSS in preparing their SBIR proposal.

For general information about CAMRSS, please contact ERIM, Public Communication at (313) 994-1200, ext. 3891.

For membership information, write or call:

Dr. Charles J. Jacobus
CAMRSS Director
ERIM
P.O. Box 8618
Ann Arbor, MI 48107
(313) 994-1200, ext. 2457 or 2738



Center researchers are exploring ways to automate space- and ground-based servicing technology as shown in this simulation of a satellite servicing system mock-up. An image understanding system coupled to robotics provides a symbolic description of the environment which can be manipulated by users.

Center for Advanced Space Propulsion

The Center for Aerospace Research, a not-for-profit venture of the University of Tennessee and Arvin/Calspan, established the Center for Advanced Space Propulsion (CASP) following award of a NASA grant in October 1987. CASP's mission is to initiate and conduct advanced propulsion research in partnership with industry.

Growth from five core projects conducted during the center's first year of operation to as many as 17 in the second highlights CASP's acceptance as an emerging force in the commercial development of space propulsion technologies.

Located at the University of Tennessee Space Institute (UTSI) Research Park, the center is also near research and test facilities at the Air Force's Arnold Engineering Development Center, UTSI and Marshall Space Flight Center. Investigators and research assistants are drawn from the University of Tennessee and Calspan's engineers and scientists.

CASP's first year experience has clearly established specific technical disciplines that represent the best match of what CASP can offer industry and what industry and NASA require. In chemical propulsion, CASP is concentrating on computational fluid dynamics analysis of rocket engine performance. In expert systems applications, the center is focusing on health monitoring and fault diagnosis, component life and assembly scheduling, fault pattern detection, and intelligent hypertext. With regard to low gravity fluid dynamics, CASP is focusing on 2-phase fluid transfer and fluid management and control. In the area of electric propulsion, the emphasis is on development of a Magnetic Annular Arc (MAARC) thruster and an ion thruster.

CASP's industrial participants include Boeing Aerospace Company, Rocketdyne Corporation, Teknowledge Inc., Symbolics Inc., Arvin/Calspan, TRW, Sundstrand, and Saturn Corporation. University participants include: University of Tennessee, University of Tennessee Space Institute, University of Alabama-Huntsville, and Auburn University. Marshall Space Flight Center and Lewis Research Center are also affiliated with CASP.

Representative projects include design, construction, and testing of a MAARC. In this project a nominal 25kw MAARC thruster using nitrogen, ammonia or hydrogen fuel will be produced for deep space mission, orbital transfer, and possibly station keeping.

CASP has also developed computational techniques for describing the inviscid flow field in the Space Shuttle Main Engine (SSME). These computer codes will be used to design high area ratio nozzles for future space propulsion systems.

In addition, a SSME Component Assembly and Life Management System is being developed by CASP to assess the remaining life of all SSME components following each ground test or flight mission.

CASP is also examining liquid oxygen transfer and storage at low gravity. In this project, the basic fluid and thermodynamic behavior involved in oxygen tank transfer is being investigated with Boeing.

For information on these and other projects of the Center for Advanced Space Propulsion contact:

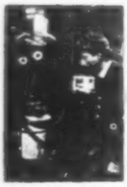
Center for Advanced Space Propulsion
University of Tennessee Space Institute
P.O. Box 1385
Tullahoma, TN 37388-8897
(615) 454-9294

Center investigators review a display from artificial intelligence software.

The Space Shuttle Main Engine mach number contour levels shown are part of a CASP effort to develop computational techniques for describing the engine's flow field.

Space Structures
And Materials

Center for the Commercial Development of Space on Materials for Space Structures



The center's Low-voltage Scanning Electron Microscope is used to examine metals, ceramics, polymers, and composite materials directly without the application of coatings and is particularly useful for viewing fractured or damaged surfaces.

Established in September 1987, the Center for the Commercial Development of Space on Materials for Space Structures is a joint effort between Case Western Reserve University's (CWRU) Departments of Materials Science and Engineering and Macromolecular Science.

The goal of the center is to provide materials for space structures that are capable of being made and/or assembled in space and capable of withstanding the space environment. In addition to their direct use in space structures, these new materials will be developed commercially for Earth-bound applications.

Industrial participants of the center include the following companies: Dow Chemical Company, Dow Corning Company, Dural Aluminum Composites Corporation, Edison Polymer Innovation Corporation, Goodyear Tire and Rubber Company, TRW, Inc., and 3M. Each company is cooperating on several of the research projects being conducted in the different areas of materials for space stations.

NASA's Lewis and Langley Research Centers are also associated with the center.

Requirements identified as important for application of materials to large space structures include a life requirement of at least 30 years, in addition to resistance to environmental and mechanical attack in low Earth orbit. Specific structural design issues include mechanical considerations, thermal fluctuations, space environmental effects, manufacturing processes and cost.

The research areas cover the types of structures most likely to be used for research and long-term habitation in space. Thin films, used as the outer form in combination with plastic foamed materials as a filler, provide the basis for expandable solid structures with highly variable internal/external shapes and a wide range of "design-in" characteristics.

Lightweight, strong organic and inorganic composites are likely to be used as the building material for structures and load-bearing elements of large structures such as the Space Station.

Projects being undertaken include:

Coatings—Construction components will require protection from the space environment hazards such as atomic oxygen and UV radiation. One project underway involves developing inorganic coatings that show resistance to these space environmental conditions.

Deformation Mechanisms of Continuous Organic Fiber Reinforced Epoxies—Fiber-reinforced plastics have gained widespread use in aerospace applications mainly because of their extremely high specific moduli and strengths. Epoxies reinforced with strong, continuous organic fibers such as graphite and Kevlar fibers have been processed and tested.

LCP/PET Blends—Thermosets and thermoplastic composites are of interest to both the aerospace and aircraft industries due to weight and processing considerations. Thermotropic "self-reinforcing" liquid crystal polymers (LCP) blended with thermoplastic polyethylene terephthalate (PET) may yield a material with optimum properties.

For more information on this center contact:

Center for Materials for Space Structures
Case Western Reserve University
School of Engineering
10900 Euclid Avenue
Cleveland, OH 44106
(216) 368-4222

The Thermal Fatigue Testing Unit can automatically cycle materials at a programmable rate and test materials that are up to seven inches long and one inch in diameter with temperatures ranging from 200°F to −150°F.

Center for Commercial Development of Space Power

Future commercial activities in space will require power levels well above those currently available. Space power systems will have to be reliable, efficient, cost effective, fault tolerant, and possess a high degree of autonomy.

The Auburn Center for Commercial Development of Space Power was established October 1, 1987, with the objectives of identifying the critical technological impediments to the economic deployment of power systems in space, advancing these technologies, and developing new products to meet the power generation, storage, conditioning, and distribution needs of commercial space users. The center is administered by the Space Power Institute of Auburn University.

Lewis Research Center has been designated as the technical affiliate of the center. In addition, the Marshall Space Flight Center has agreed to provide close technical support.

The center maintains a partnership with its industrial members, with the partners providing valuable input on commercial opportunities, which is used to determine which research projects will be pursued. Industrial partners include AT&T Bell Laboratories, Maxwell Laboratories, Rocketdyne Division of Rockwell International, and Westinghouse R&D Center.

Other academic institutions affiliated with the center are Florida A&M University, University of South Carolina, University of Tennessee Space Institute, and State University of New York at Buffalo.

The center receives personnel support and the use — on a non-interference basis — of specialized facilities at the following: Lewis Research Center, Marshall Space Flight Center, Air Force Wright Aeronautical Laboratories, Hanford Engineering Development Laboratories, National Institute of Standards and Technology, and Sandia National Laboratory.

The center's research program is synergistic among several elements, each of which may be critical in a specific space power application.

These areas are:

- Power distribution, control and management
- Discrete energy/power sources
- Advanced power system sensors
- Power conditioning
- Power transmission

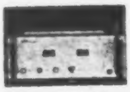
Each research project within the center offers the promise of commercial potential. At the same time, complete systems are required for space power applications. This necessitates integration of all research areas in the program. The result is an overall technology focus, which is outlined in Figure 1.

The current research program underway will provide the basis for developing complete power system packages, tailored to specific user needs.

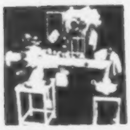
An example of the work underway deals with the design and fabrication of power conversion equipment. This project involves the investigation of candidate circuit topologies for specific applications to determine their impact on issues such as weight, efficiency, component stress, and reliability. ☐

For more information on the Center for the Commercial Development of Space Power contact:

Dr. Raymond Askew
Space Power Institute
Auburn University
Auburn, AL 36849-5320
(205) 844-5894



A new commercial line of capacitor charging power supplies resulted as a spinoff of new technology developed from CCDS power research.



Scientists conduct research in the Space Power Institute hypervelocity launch facility and space environmental test chamber

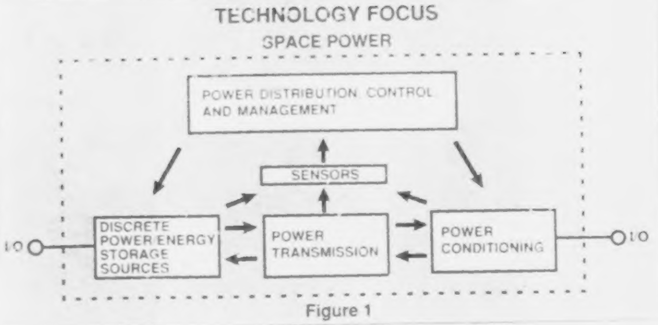

TECHNOLOGY FOCUS
SPACE POWER
POWER DISTRIBUTION, CONTROL AND MANAGEMENT
SENSORS
DISCRETE POWER/ENERGY STORAGE SOURCES
POWER TRANSMISSION
POWER CONDITIONING
I/O
I/O

Figure 1

Center for Space Power

Space Stations, unmanned platforms, and lunar bases represent just a sampling of current space programs planned for the future. With these developments nearing reality, a key factor in their success is the readiness of power systems to support pioneering efforts and permanent habitation in space.

The Center for Space Power at College Station, Texas, is at the forefront of power systems research. The center's goal is to demonstrate in the next five years that providing power in space is indeed a viable commercial activity.

Center activities involve collaboration of researchers and engineers from university and corporate entities working to develop critical space power technologies. A systematic approach starting with market studies and technology assessments is being followed by specific research and development tasks on materials, components, systems, and services essential to space power.

Established by NASA in 1987, the Center for Space Power is operated as a unit of the Texas Engineering Experiment Station, a state agency dedicated to promoting research and high technology.

The Center for Space Power provides these services:

- Identifies and conducts research to enhance space power systems technologies;
- Brings together expertise and excellence among interdisciplinary researchers for the analysis, design, fabrication, and operation of space power systems;
- Facilitates technology interchanges between companies and universities through cofunded projects;
- Enhances education programs for the training of space technology professionals;
- Sponsors symposia and similar activities;
- Assists companies in recruiting qualified students for employment and research studies, and
- Promotes communication among researchers, NASA, other agencies, and industry.

Other benefits to participants include the following:

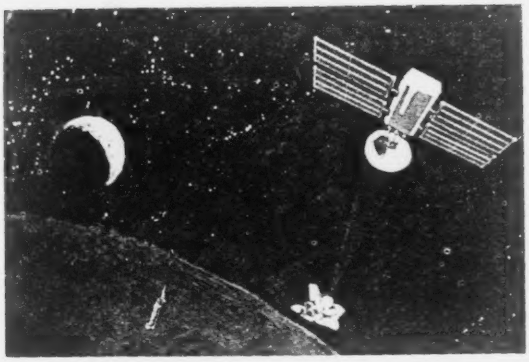
- Providing financial leverage by maximizing research and development investments through cofunding;
- Accelerating development of space-related commercial products;
- Training personnel by providing unique opportunities for research and continued technical education;
- Facilitating access to space flight opportunities;
- Developing contacts between industry and academia; and
- Expanding commercial opportunities and markets in space.

Research interests include power systems for individually designed applications — such as a communication satellite or Space Shuttle — and for future needs such as Space Stations, man-tended free fliers, lunar bases, and other powered installations.

Short-term projects include improving individual components currently used in space power systems, such as batteries, fuel cells, solar panels, and power conditioning. Long-term projects address the development of new power systems using photovoltaics, solar dynamics, and nuclear systems for power production — or a combination — with power distribution through hardwiring or microwave laser transmission.

For more information on the Center for Space Power contact:

Center for Space Power
Texas Engineering
Experimentation Station
The Texas A&M
University System
College Station, TX
77843-3118
(409) 845-8768



An artist's rendition of microwave power transmission illustrates one of the major projects being conducted by the Center for Space Power.

Reproduced from The Future of the Land Remote Sensing Satellite System (Landsat), by Karl A. Rohrer and Marcia S. Smith. Washington, Congressional Research Service, 1989. 13 p.

THE FUTURE OF THE LAND REMOTE SENSING SATELLITE SYSTEM (LANDSAT)

USES OF REMOTE SENSING DATA

Land remote sensing data are used for a variety of purposes, including agricultural forecasting, land management, cartography, mineral exploration, pollution monitoring, demography, disaster warning and land use planning.[1] Users include U.S. Government agencies, primarily the Departments of Agriculture, Defense, Interior and State and the National Aeronautics and Space Administration (NASA), foreign governments, universities and private companies.[2] The current U.S. land remote sensing system--Landsat--is operated by the Earth Observation Satellite Company (EOSAT) under contract to the National Oceanic and Atmospheric Administration (NOAA), part of the Department of Commerce. Landsat data and imagery are received, processed and marketed by EOSAT.

HISTORY OF LANDSAT COMMERCIALIZATION

The first civil land remote sensing satellite, Landsat 1, was launched by NASA in 1972.[3] Since then, four more Landsat spacecraft have been developed and launched. Landsat 1 - 3 are no longer operating. The current Landsat system consists of two satellites: Landsat 4 and 5, launched in 1982 and 1984, respectively.

In 1979, operational responsibility for the Landsat system was transferred from NASA to NOAA. The Carter Administration, confident of the commercial potential of remote sensing data, began the process of privatizing the Landsat system. The private sector was expected to assume ultimate responsibility for operating the system once a commercial market for the data developed; that market development process was expected to take as long as a decade. The Reagan Administration, in its push to privatize a number of Government operations, accelerated the commercialization of Landsat and in 1984, Congress passed the Land Remote Sensing Commercialization Act (P.L. 98-365) to facilitate transfer of operational responsibility of Landsat to the private sector.

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[1] Other types of remote sensing, including ocean sensing and weather satellites, are not discussed in this report.

[2] A good review of how remote sensing data are utilized by Government and private users was presented at hearings held by the House Science, Space and Technology Committee in March and April 1987, entitled *The Future of the Landsat System*. U.S. Congress. House. Committee on Science, Space and Technology. The Future of the Landsat System. Hearings, 100th Congress, 1st Session. March 31 and April 2, 1987. Washington, U.S. Govt. Print. Off., 1987.

[3] Originally, Landsat was called the Earth Resources Technology Satellite (ETRS) program; the first satellite was designated ERTS-1. It was renamed Landsat 1 after the program name changed.

Through a competitive bidding process, NOAA selected EOSAT in September 1985 to operate the Landsat system under contract. EOSAT, a joint venture between Hughes Aircraft (now owned by General Motors) and RCA (later bought by General Electric), agreed to assume responsibility for marketing and distributing existing Landsat data, operating Landsat 4 and 5 under contract to the Government, and building two new spacecraft (Landsat 6 and 7), including necessary ground systems. Because the market for remote sensing data was considered undeveloped, the U.S. Government agreed to provide $250 million over five years as a subsidy to assist in the commercialization of Landsat. At that time, both EOSAT and NOAA agreed that two more satellites were needed to assure potential users of data continuity. In addition to the $250 million subsidy to EOSAT, the Government agreed to pay launch costs for the two new satellites. Originally planned for launch on the space shuttle in 1988 and 1992, launch costs were estimated by NASA at $45 million. Thus, at the time of the original contract, the total U.S. Government commitment to the commercialization of the Landsat system was $295 million.

The Landsat commercialization process was complicated by two events in January 1986. First was the Administration's decision to eliminate any further funding for Landsat commercialization in the FY87 budget submission. The Administration's position was that Government funding for Landsat commercialization could not go beyond the $125 million already appropriated[4] and that all additional investments in the Landsat system would have to come from EOSAT or other private sources. Second was the space shuttle *Challenger* tragedy which had many repercussions for the space program; one of the most immediate was the disruption of near-term U.S. launch capability.

The problems with Landsat commercialization were compounded by EOSAT's request (made in the fall of 1985) to change the spacecraft platform design from the TIROS concept, used for previous Landsats, to the OMNISTAR platform. EOSAT felt that the OMNISTAR platform, which could be serviced and re-configured on-orbit by space shuttle crews, would enhance its chances of making remote sensing commercially viable. EOSAT's request stipulated that there would be no additional costs to the Government for these changes. In March 1986, NOAA approved EOSAT's design change request, even though it meant the program would be shuttle-dependent at a time of uncertainty in the shuttle program.[5]

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[4] $90 million was paid to EOSAT to support the commercialization contract; $35 million to NASA to pay for space shuttle launches.

Why NOAA and EOSAT decided to move to a shuttle-dependent design weeks after the *Challenger* tragedy is not clear. Perhaps they did not realize its impact on U.S. launch capabilities. Apparently, they also did not anticipate the growing debate over the use of the shuttle launch facility at Vandenberg Air Force Base, where U.S. payloads are launched into polar orbits.[6] The Air Force has since decided to mothball the Vandenberg space shuttle launch facility indefinitely. It is probable that it will never be used for space shuttle launches.

Congress disagreed with the Reagan Administration's new position that the Government would not provide the rest of the promised subsidy to EOSAT and restored $27.5 million for Landsat commercialization in the FY87 Continuing Appropriation Act (P.L. 99-500). However, since Congress had not yet received a formal proposal from the Administration to continue the commercialization effort, obligation of the FY87 funding was subject to NOAA submitting and Congress accepting a new Landsat commercialization proposal (including funding plans), which ultimately did not happen until October 1987.

NOAA sent its first revised commercialization plan for Landsat to Congress in December 1986. This revised NOAA plan called for only one more Landsat spacecraft based on the TIROS platform design, instead of the two originally planned, for a total cost to the Government of $259.2 million,[7] and requested $62.5 million in FY87 funding. At this time, the launch vehicle for any new Landsats was shifted from the space shuttle to a Titan II expendable rocket. Congress rejected NOAA's plan and continued to hold up the release of the FY87 funds because it felt that a commitment to only one more satellite was insufficient to develop the required confidence in the system necessary to attract data users which would lead to a successful commercialization effort. As a result of this policy dispute (and lack of funding), EOSAT began laying off employees in December 1986 and ceased all marketing and spacecraft design activities.[8]

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[5] A spacecraft using the OMNISTAR design can be launched on a Titan IV launch vehicle instead of the shuttle. However, the Air Force has already committed to using all the Titan IVs available through the early 1990s. It is unlikely that one would be available to launch Landsat. In addition, since the OMNISTAR platform can only be serviced by the shuttle, launching it on a Titan IV would not significantly reduce its dependency on the shuttle.

[6] Landsat and other satellites intended to observe the entire globe are placed in "polar" orbits that circle the Earth's poles. For safety reasons, these launches take place from Vandenberg where the path of the launch vehicle is over the ocean rather than land.

[7] $209.2 million for the satellite and $50 million for one Titan II launch, the cost quoted by the Air Force at that time.

The Landsat commercialization debate was revisited in the spring of 1987. Congress, responding to Administration inaction on the issue, adopted language in the FY87 Supplemental Appropriation (P.L. 100-71) which allocated $62.5 million of previously appropriated funds to continue Landsat commercialization: the $27.5 million for Landsat from the FY87 Continuing Resolution plus $35 million from NOAA's polar orbiting satellite program.[9] This measure was passed by Congress in June 1987, but the release of the funds remained contingent upon congressional approval of a Landsat commercialization and funding plan.

NOAA submitted a new commercialization plan to Congress in June 1987 which was a slight modification of the December 1986 proposal; it called for one additional satellite (Landsat 6) and the study of a second satellite that might include more advanced or commercially oriented sensors. This plan was initially rejected by Congress (which continued to press for a two satellite system), but later approved in October 1987,[10] clearing the way for the release of the FY87 monies. However, actual release of the $62.5 million in FY87 funding was delayed once again, pending renegotiation of the EOSAT contract.

Because the release of the FY87 funding was approved so late in the year, no FY88 monies were appropriated to NOAA for support of the EOSAT contract. However, $10 million was appropriated to the Department of Defense in the FY88 Continuing Appropriation Act (P.L. 100-202) to support Landsat 6 requirements and later transferred to NOAA.

In April 1988, after four months of negotiation, the EOSAT contract was modified again to make the contract consistent with the current and approved Landsat commercialization plan. At that time, the FY87 funding was finally released. Under the terms of the present agreement, Landsat 6 will be a TIROS-based spacecraft, launched on a Titan II. The costs of developing

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[8] However, EOSAT developed its own commercialization proposal. In February 1987, EOSAT proposed a revised Landsat program to NOAA: two TIROS-based spacecraft and a new ground system (basically the terms of the original 1985 contract) for a total cost of $366.8 million, including $70 million for two Titan II launches. The EOSAT proposal failed to marshall either Administration or congressional support.

[9] The $35 million transferred from NOAA's polar orbiting satellite program had been redirected from NASA to NOAA in the FY87 Continuing Resolution. It was originally appropriated to NASA in FY85-86 to pay for Landsat launch costs.

[10] A review of the various Landsat commercialization plans is provided in Appendix I.

Landsat 6 and associated ground systems are not to exceed $220 million (excluding launch costs). Any additional costs will be absorbed by EOSAT. In addition, EOSAT agreed to refund up to $10.8 million to the Government under an innovative "pay-back" arrangement whereby EOSAT will pay NOAA the first $2.5 million of annual Landsat marketing revenues for four plus years, up to a total of $10.8 million.[11] This lowers the total cost to the government of developing Landsat 6 to $209.2 million. In addition, the Air Force has now reduced the cost of launching Landsat 6 on a Titan II to $36.5 million.

Through FY89, a total of $182.9 was appropriated by the U.S. Government to support the EOSAT contract.[12] For a review of Landsat commercialization funding history, see Appendix II. NOAA has requested $36.9 million in FY90 to support the EOSAT contract and continued development of Landsat 6. No launch vehicle for Landsat 6 has been procured yet. Congress rejected a FY89 NOAA request to begin payments to the Air Force for a Titan II to launch Landsat 6 in 1991, stating that launch costs for Landsat 6 are to be deferred and are to come from a source other than NOAA (P.L. 100-459). However, NOAA is concerned that without the advance payment, the Air Force will not reserve a launch vehicle.[13]

STATUS OF EXISTING LANDSAT SYSTEM

The current Landsat system consists of two satellites, Landsat 4 and 5, and associated ground infrastructure (ground stations, processing centers, distribution facilities). Landsat data are used in over 100 nations primarily by national governments (the U.S. Government alone is responsible for over 50% of EOSAT's business), but also by universities, international organizations and private companies. According to EOSAT, its current revenues from the operation of the Landsat system total nearly $15 million annually: approximately $7 million from ground station fees, and $7-8 million from sales of Landsat imagery and other products.[14] This aspect of commercialization has been relatively successful; in fact, EOSAT has significantly reduced operations costs for Landsat 4 and 5 from $36 million a year to $18 million a year.[15] EOSAT expects improvements in its operational efficiency to continue.

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[11] The first $2.5 million payment was due March 31, 1989, but according to EOSAT, has not yet been paid. There have been discussions between EOSAT and the Government about applying the $2.5 million to support continuation of Landsat 4 and 5 operations. EOSAT is currently working with NOAA on the issue and awaiting specific instructions on how to proceed with the payment.

[12] This includes $172.9 million to NOAA and $10 million to the Department of Defense (later transferred to NOAA).

[13] In the FY90 budget submission, NOAA projects that a Titan II will be procured in FY91 at a cost of $36.5 million.

[14] These figures were estimates provided by EOSAT during congressional testimony in March 1989.

NOAA had anticipated that Landsat 4 and 5 would cease operation by 1987, but both satellites have greatly exceeded their design lifetimes and continue to provide useful data even though some of their systems are no longer functioning. Since Landsat 6 will not be available until 1991, EOSAT wants to keep the satellites operational as long as possible. However, NOAA did not request any operations funding for Landsat in FY89, even though it expected that $26 million would be needed. Congress added $9.4 million to the FY89 NOAA appropriation (P.L. 100-459) to cover Landsat operations for half of the fiscal year, and directed NOAA to develop a plan to fund operations for the rest of the year. In early 1989, however, NOAA stated that it did not have any funding available for Landsat operations after April 1 and directed EOSAT to turn the satellites off.

The National Space Council[16], chaired by Vice-President Quayle, developed an interim funding plan in early March that will allow Landsat operations to continue through early summer 1989. Government agencies which use Landsat data are contributing to the fund; the total amount of funding and the number of months it will cover are still being worked out by the Space Council, but to date, the Department of Defense has pledged $3 million and NASA, $1 million. The Landsat shutdown order was rescinded by NOAA in mid-March pending resolution of the interim funding issue. Both Landsat 4 and 5 are expected to remain operational for at least another six months and perhaps even until 1991, although a catastrophic failure could occur at any time.

FUTURE LANDSAT SPACECRAFT

Landsat 6

After an 18 month shutdown due to funding uncertainty, EOSAT restarted development work on Landsat 6 in April 1988. Work is proceeding on schedule for a July 1991 launch. Landsat 6 will be based on an advanced TIROS-N platform design and will carry an Enhanced Thematic Mapper sensor with imaging capability in seven bands with 30 meter resolution, and

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[15] Based on testimony presented by NOAA and EOSAT at hearings held by the House Science, Space and Technology Committee in March 1989, entitled *Proposed Termination of Landsat 4 and 5.*

[16] The National Space Council was reestablished by Congress as of February 1, 1989 to coordinate U.S. space policy; the original council, created in 1958, was abolished by President Nixon in 1973. The Council is part of the White House and is chaired by the Vice President.

15 meter panchromatic resolution (the Thematic Mappers on Landsat 4 and 5 also have 30 meter resolution). EOSAT is also developing a sea-wide field sensor (Sea-wifs) to provide ocean color and temperature information. EOSAT considered adding a five-meter, full color, satellite tracking and reporting sensor (STAR), but determined there was not a substantial enough market to support its development and operations costs. EOSAT believes it is likely that STAR technology would be incorporated into Landsat 7.

Landsat 7

As a part of the FY88 appropriation, Congress set aside $2 million for NOAA to study the possibilities for commercial remote sensing systems after Landsat 6. Three separate studies were prepared by independent contractors and recently released by NOAA. The studies all concluded that a fully commercial remote sensing system probably will not be commercially viable and competitive until early in the next century without significant Government support. Three major reasons were cited: a limited market for data, the high costs of improving technology and foreign competition.[17]

No decision to move forward with a Landsat 7 has been made by either NOAA or EOSAT, although EOSAT has conducted some in-house feasibility studies of Landsat 7 concepts. However, in the 1988 contract modification, EOSAT agreed to waive all rights to market data from follow-on civil land remote sensing satellites, unless the Government decides to have EOSAT develop that follow-on satellite. The modification also directed EOSAT to suspend any work on the development of Landsat 7, essentially halting further commercialization of Landsat for the time being. This gives the Government additional flexibility in redirecting future Landsat commercialization policy.

INTERNATIONAL COMPETITION

The debate over the future of Landsat is not taking place in a vacuum. Current and future Landsat satellites face stiff competition from foreign nations which have developed their own remote sensing capabilities and are actively marketing the data. Today remote sensing data are available from the

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[17] The Egan Group. Study for Advanced Civil Earth Remote Sensing System: Focused Finance Study. Washington, D.C., The Egan Group, August 1988.

KRS Remote Sensing. Study for an Advanced Civil Earth Remote Sensing System (2 volumes). Landover, Maryland, KRS Remote Sensing, August 1988.

The Analytical Sciences Corporation. A Study of Advanced Civil Earth Remote Sensing System. Reading, Massachusetts, The Analytical Sciences Corporation, August 1988.

French SPOT system or from the Soviet Union. Both offer better resolution[18] than Landsat, although the sensors on the French and Soviet systems do not include some of the spectral bands available on Landsat (those specialized for imaging in the thermal bands). Thus, many users obtain data from both Landsat and SPOT. SPOT provides black and white data with 10 meter resolution, and color data with 20 meter resolution.

The Soviet Union recently began marketing remote sensing data as well. Although they have the best resolution of all the systems currently available (5 meters), the Soviets must launch a dedicated spacecraft to obtain the data after the order is placed, rather than using archived or real-time data. In fact, the Soviets still use actual photographic film that is exposed in orbit and ejected in a capsule that is recovered on Earth. Thus, the time between request and filling the order may be longer than with the Landsat and SPOT systems which continuously return data to Earth in digital form. The Europeans and the Japanese are also planning remote-sensing satellites. It is not yet clear what their commercial interests are in this area.

In late 1988, NOAA initiated discussions with CNES (the French space agency) to discuss development of an international commercial civil land remote sensing satellite for the late 1990s. NOAA's action was in response to a congressional directive to examine options for future U.S. Government involvement in commercial remote sensing. The discussions with the French are apparently one of several partnership ideas being explored by NOAA for future commercialization of the Landsat system (Landsat 7 and beyond). NOAA's actions were not well-received by other Government agencies. The State Department reprimanded NOAA for failing to inform it (and other agencies) of such discussions with a foreign government.[19] NOAA also failed to inform EOSAT of the talks, even though SPOT Image, the French commercial contractor, was actively supporting CNES. Despite industry skepticism about a joint international commercial remote sensing satellite system, NOAA and CNES have formed a joint working group to study the feasibility, cost and schedule associated with the joint commercial concept. The first report of the study group is expected in June.

ISSUES

Near-term Operations Funding for Landsat 4 and 5

Although the issues surrounding commercialization are complex, it is the consensus of Government, academic and business experts that the Landsat system is a valuable resource which must be protected. The data are valuable for national security and economic purposes, and continued work in the area of remote sensing technology is needed for the U.S. to maintain its competitiveness in an increasingly competitive marketplace. The only unresolved issue is how to pay for it. In the near-term, continued operations of Landsat 4 and 5 will dominate the debate.

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[18] Resolution is the ability to "see" an object of a certain diameter or larger.

[19] Covault, Craig. Landsat/Spot Merger Talks Spark Debate on Commercial Space Venture. Aviation Week and Space Technology. January 23, 1989, p. 20.

NOAA's position is that both satellites are operating well beyond their expected lifetimes, and that EOSAT is getting more data than it could have ever anticipated when it assumed control of the system in 1985. NOAA feels that EOSAT and the Government user agencies should pay continuing operations costs. EOSAT claims that sporadic and continually fluctuating Government subsidies and changes to the original contract have made it impossible to develop a consistent market which could support all operating expenses. It believes that any profits should be invested in developing Landsat 6 and improving the efficiency of their operations, not paying for operations. The user agencies have reiterated that NOAA was charged with responsibility for the Landsat system and they should stand up to their responsibility and fund Landsat 4 and 5 until they become inoperable.

The National Space Council's recent move to continue operations is a short-term solution. The emergency funding only pays for Landsat 4 and 5 operations through the early summer of 1989. The issue of funding for the rest of FY89, FY90 and FY91 (if the satellites remain operable) remains to be resolved.

Long-Term Commercial Viability of Landsat

As Congress continues to debate the future of the Landsat system, some of the policy options it may consider include:

Continued Government support of Landsat. One option is for the U.S. Government to scale back the attempt to fully commercialize Landsat, and instead turn the Landsat program into a public-private partnership, operated by a private company with an annual and consistent Government subsidy. A guaranteed subsidy would enable a commercial operator to develop and expand markets, improve the system's efficiency and most likely increase profitability in the long-term. However, this would dampen the Government's privatization efforts and would continue to require substantial Government funding in a time of increasing fiscal austerity.

Government control of Landsat. Some have suggested that the commercialization of Landsat was premature, and that until a true commercial market develops, control of the Landsat system should be returned to the U.S. Government. This would require the U.S. Government to choose an agency to take responsibility for operating the system and developing new satellites. Among the options are NOAA, NASA, the Department of Defense or the

Department of Interior. This option would probably cost the government the most money, but would provide the maximum assurance of data availability.

Termination of Landsat program. If the U.S. Government decides that it cannot afford to continue to invest in the Landsat system, and the private sector cannot develop a market large enough to sustain commercial operations, Landsat could be terminated. This would force U.S. Government and private users to rely on data from other countries.

International Cooperation in Future Remote Sensing Ventures. Another alternative is international cooperation in design, development and operation of a commercial remote sensing satellite system. Whether it is on a multilateral or bilateral level, cooperation could eliminate competition for a limited market, reduce development costs for new technologies and significantly reduce the amount of Government subsidies needed to operate such a system. However, negotiation of a operational framework for such a for such a system would be difficult and time-consuming, as would the development and implementation of day-to-day management processes and procedures. The United States might also suffer a loss of prestige since it was the pioneer in developing these technologies.

APPENDIX I

Landsat Commercialization Plans and Cost Estimates

(costs in $ millions)

Plan	Number of Satellites	Design	Launch Vehicle	Government Subsidy to EOSAT	Government Paid Launch Costs	TOTAL
1985 EOSAT Contract	2	TIROS	Shuttle	$250.0	$45.0	$295.0
1986 Modified Contract	2	OMNISTAR	Shuttle	$250.0	$45.0	$295.0
1986/1987 NOAA Commercialization Plan[1]	1	TIROS	Titan II	$209.2	$50.0	$259.2
1987 EOSAT Proposal	2	TIROS	Titan II	$296.8	$70.0	$366.8
1988 Modified Contract	1	TIROS	Titan II	$209.2[2]	$38.3[3]	$247.5

Table prepared by CRS based upon data from NOAA, EOSAT and Congressional reports.

1. The 1986 NOAA commercialization plan called for only one satellite; it was rejected by Congress. The 1987 revision called for only one satellite and study of the feasibility of a second satellite.

2. Under the terms of this contract modification, the costs of developing Landsat 6 are not to exceed $220 million; EOSAT has agreed to refund the Government up to $10.8 million, bringing the actual Government subsidy to $209.2 million.

3. Launch costs are subject to change. In fact, the current Air Force estimate for launching Landsat 6 is now $36.5 million.

APPENDIX II

Landsat Commercialization Funding History

(costs in $ millions)

1985 EOSAT Contract

	FY 85-86	FY 87	FY 88	FY 89	TOTAL
EOSAT	$90.0	$87.0	$55.0	$18.0	$250.0
NASA[1]	$35.0	$10.0			$45.0

1986/1987 NOAA Commercialization Plan

	FY 85-86	FY 87	FY 88	FY 89	TOTAL
EOSAT	$90.0	$44.5	$50.6	$24.1	$209.2
Air Force[1]		$18.0	$12.0	$20.0	$50.0

1988 Modified EOSAT Contract

	FY 85-86	FY87	FY88	FY89	FY90	FY91	TOTAL
EOSAT	$90.0	$62.5	$0.0	$24.1	$32.6		$209.2[2]
Air Force[1]				$10.0	$24.3	$4.0	$38.3

Actual and Planned Landsat Commercialization Funding

		Appropriations			*Request*		
	FY 85-86	FY87	FY88	FY89	FY90	FY91	TOTAL
EOSAT	$90.0	$62.5	$10.0[3]	$20.4	$36.9		$219.8[2]
Air Force[1]						$36.5[4]	$36.5

Tables prepared by CRS based upon NOAA budget data.

1. Launch costs for Landsat satellites are not part of EOSAT subsidy, but as part of the commercialization agreement, are paid directly by the Government.

2. Contract states that Landsat 6 development costs are not to exceed $220 million. EOSAT has agreed to refund the Government $10.8 million from Landsat revenues, so the actual Government subsidy will total $209.2 million.

3. Funds provided to the Department of Defense for Landsat 6 development in FY88 Continuing Appropriation (P.L. 100-202), and later transferred to NOAA.

4. Proposed request for FY91. Congress rejected a FY89 NOAA request to begin procurement of a Titan II launch vehicle from the Air Force, however.

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Marcia S. Smith, Specialist in Aerospace Policy, Science Policy Research Division, Congressional Research Serivce.

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE ITS MILITARY USE OF SPACE.

MILITARY SPACE FORCES

THE NEXT FIFTY YEARS

SUMMARY

Space, the newest military medium, demands innovative strategies, tactics, and force postures to complement those for land, sea, and air. This study, predicated on present technologies and predicted improvements during the next 50 years, concentrates on the Earth-Moon System, because interplanetary combat seems farther in the future.

Four discrete regions are discernable: Earth and Atmosphere; Cirumterrestrial Space; Moon and Environs; and Outer Envelope. Strategically significant key terrain, the seizure, retention, destruction, or control of which could confer decisive advantage within those regions, includes critical space installations on Earth; critical military and civilian installations on the moon and in orbit; geostationary and polar Earth orbits; and lunar libration points.

Threat to interests and objectives in space are difficult to assess, because many traditional indications are inapplicable, and little is objectively knowable. Tactical warning times, often measured in milliseconds, put a premium on accurate predictions, but present enemy capabilities and intentions pose special problems for intelligence analysts, in ascending order of complexity.

Sound policymaking, planning, and programming are particularly desirable during early stages of the Space Age, since far-reaching decisions made in the near future will have long-term ramifications. Deployable forces and infrastructures both deserve careful attention, with special concern for survivability, adaptability, and responsiveness. Sufficient quantities, satisfactory qualities, and the best mix of manned/unmanned, offensive/defensive, and combat/support forces are topics for consideration.

U.S. and Soviet military space forces emphasize missions that support armed services on Earth. Neither deploys extensive space combat capabilities. Neither defends space satellites effectively. The Soviets, however, are laying a sounder foundation for military space power. Impressive surge and reconstitution abilities would serve them well in wartime, compared with U.S. counterparts, which are too few to play tit-for-tat, maintain hign-tempo operations very long, or replace combat casualties expeditiously.

The study terminates with seven cost-effective options that might strengthen deterrence and improve U.S. combat capabilities, if deterrence should collapse. Seven "big ticket" programs comprise a second list that senior U.S. officials could consider, if additional measures seem prudent.

Reproduced from Military Space forces, the next fifty years, by John M. Collins. Washington, Congressional Research Service, 1989. p. 38-66, 122-135. (CRS Report to Congress 89-578 RCO)

Chapter 2

STRATEGIC PROBLEMS AND OPTIONS

Space, the newest military medium, needs a distinctive school of strategic thought to complement land, sea, and air counterparts in ways that assist the development of cohesive plans and programs.1/ Elements, as a minimum, should include politico-military purposes, principles, and threat indicators, together with theories and concepts that address deterrence, offensive/defensive operations, and arms control. The product could help planners create sound strategies that match ends with means (a measure of effectiveness) while minimizing waste (a measure of efficiency), despite enemy countermeasures and inescapable limitations (such as resources and expertise).

POLITICO-MILITARY PURPOSES

A clear sense of purpose at the highest levels must underpin space strategies. National security interests, coupled with implementing objectives, indicate what must be done to achieve desired ends.

SECURITY INTERESTS IN SPACE

Every country and coalition on Earth has political, economic, military, social, and scientific interests in space. Survival, by definition, is the only vital interest. Physical security, prosperity, power, progress, and freedom of action are universally important. Additional interests of similar magnitude, such as peace and stability, appeal to some, while others spurn them or assign low priorities.2/

Nearly every interest in space has potential security implications. Economic competition on the moon or Mars, for instance, could cause war.3/ Scientific probes to advance understanding of our universe could have serendipitous consequences comparable to Einstein's Special Theory of Relativity, which unexpectedly paved the way for nuclear weapons.4/

This study singles out three competitive, perhaps incompatible, interests with sweeping significance: political cooperation; economic exploitation; military power.

Political Cooperation

Political cooperation, the most widely professed interest in space, conforms with the Charter of the United Nations (UN), which seeks to create "conditions of stability and well-being" that must accompany "peaceful and friendly" international relations. Ninety-six nations subscribe to the Outer Space Treaty of 1967 (Annex C). Article I specifies that exploration and other endeavors "shall be carried out for the benefit . . . of all mankind." Article II disapproves sovereignty anywhere in space. The Moon Treaty of 1979 has attracted only seven parties, none of whom now have space capabilities, but its explicit restrictions seem to reflect prevailing UN views: "Neither the surface nor the subsurface of the moon [or other celestial bodies within the solar system] . . . shall become property" of any person, state, or other organization.5/*

National leaders generally live in a less altruistic world, but openly proclaim that collaboration serves the common good better than zero-sum games with only one winner. They also agree that community efforts are preferable to hegemony by any power in space, if public statements reflect true sentiments. Responsible authorities rarely release opinions that oppose equal opportunities to share rewards and risks. The strength of such convictions will be tested when economic competition quickens in space.6/

Economic Exploitation

Economic interests in space center on vast and diversified raw materials, inexpensive solar power, and industrial techniques made possible by near vacuum and low gravity. Prospects for extraordinary productivity and growth are within relatively easy reach of planet Earth.7/

The lunar mantle contains all essential elements for the full range of manufacturing and construction on a grand scale, plus so much oxygen that some call the moon "a tank farm in space." Smelters could rely less on costly chemical treatments, because heat alone would remove most impurities from many ores in that environment. Waterless cement, specialty alloys, exotic composites (such as glass/metal mixtures stronger than steel, yet transparent as crystal), powder metallurgy, cold welding, free fall casting, and superconductors represent a few among many processes and products that plants in space could facilitate. "Sanitation engineers" could dispatch unconvertible waste on trajectories that collide with the sun or disappear in deep space.8/

Interests in economic exploitation of space are intrinsically neither virtuous nor evil. Efforts that benefit the world community could foster strategic stability. Peaceful competition, such as that in Antarctica (where seven countries have staked out territorial claims), is theoretically possible.* Efforts by any superpower or collection of states to monopolize the bounties of space and couple them with earthbound assets, however, might trigger international strife, because success in some circumstances could sensationally upset the global balance of power.

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*Australia, Austria, Chile, the Netherlands, Pakistan, the Phillipines, and Uruguay were parties to the Moon Treaty in 1989, when this report was published.

Military Power

Space, the ultimate "high ground," overarches planet Earth, its occupants, and all activities thereon. Effective use of that medium for military purposes therefore may be needed to safeguard national interests in survival, security, peace, power, stability, and freedom of action.

Every technologically advanced land, sea, and air service already depends on space satellites to such a degree that traditional command, control, communciations, and intelligence (C^3I) skills may languish, much like pocket calculators made slide rule proficiency rare. Reliance continues to increase, because systems in space offer strategic and tactical advantages that are otherwise unavailable: national technical means of verification for treaty compliance and crisis monitoring; geodetic surveys to assist military map makers and target planners; weather prediction; early warning and post attack assessment; nuclear detonation detection; global positioning/navigation data; and observable order of battle information. Satellites relay most military intercontinental telecommunications and an increasing share of tactical traffic.9/

Military interests in space almost surely will intensify and spread during the next decade. How smoothly they will mesh with aforementioned interests in political cooperation and economic exploitation is problematic. Reconciliation and collision are divergent possibilities. Plans that address both extremes and contingencies between seem advisable, pending clarification.

SECURITY OBJECTIVES IN SPACE

Politico-military objectives in space, as elsewhere, specify what any country or coalition must do to support or dispute security interests during peacetime and war *(see Figure 2 for sample options)*. Force goals that feature

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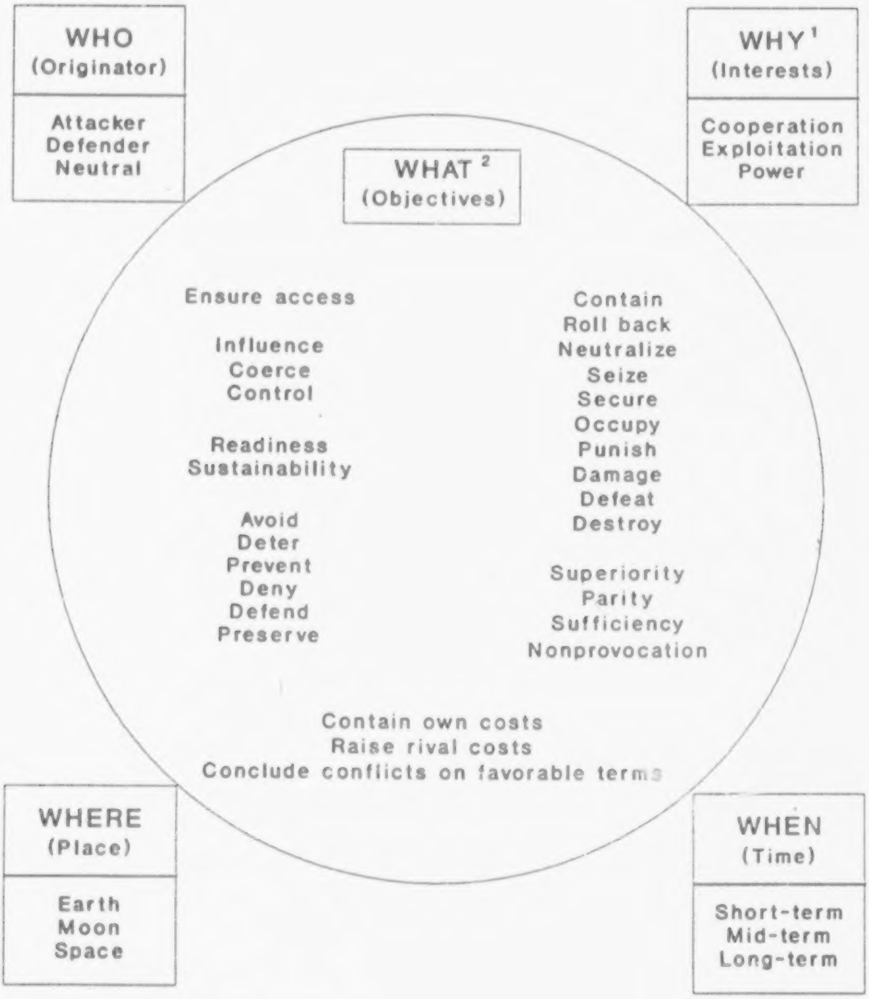
*Disputes in Antarctica, another forbidding frontier, thus far have been peaceful, perhaps because occupation remains sparse and exploitation minimal. Rich strikes that intensify economic interests could sour relations rapidly. Claimants include Argentina, Australia, Chile, France, New Zealand, Norway, and United Kingdom. The United States and Soviet Union recognize no claims, but reserve rights to make future claims of their own.10/

Figure 2
MILITARY OBJECTIVES MATRIX



[1] Sample Interests

[2] Sample Objectives

parity and nonprovocation, for example, might promote political cooperation. Quests for supremacy, which mesh well with interests in military power, probably would not. Parties that hope to satisfy economic interests in space must maintain ready access to resources on the moon and beyond, despite opposition if necessary, and perhaps deny access to competitors who seek monopolies.

Goals on Earth and in space must be complementary. Gaps and incompatibilities otherwise occur. Determination to preserve land, sea, and air links in the C^3I chain, but not satellites on which they depend, would weaken the whole apparatus. Major powers that seek to deter and, if necessary, deal decisively with coercive acts and armed aggression on this planet may find those tasks increasingly formidable, perhaps unachievable, if they cannot fulfill identical aims in space. Such interconnections are almost endless.

Short-, mid-, and long-term objectives vary in value. Most are complex. Strategists therefore must break them into component parts before assigning priorities. The remainder of this section, which illustrates that process, describes three subdivisions of the basic objective called "control": arms control; terrain control; and attitude control.

Control Arms

Arms control agreements should leave signatories more secure than unrestrained force postures. Mutually acceptable accords could relax international tensions; reduce risks of war; limit conflict types and intensities if war should erupt; decrease vulnerabilities and costs; increase those of rivals; impede, preserve, or open doctrinal/technological options; or convey a particular impression for psychological purposes.11/

It probably is too late to reverse the militarization of space, which is well under way.12/ Arms control objectives, however, could still influence developments and deployments in at least five significant ways:

- Limit/ban military installations
- Limit/reduce armed forces
- Limit force characteristics
- Limit force modernization
- Limit military activities/functions

The Outer Space Treaty, signed by 96 nations, formally proscribes military bases, installations, fortifications, maneuvers, and weapon testing of any type on the moon or other celestial bodies. It further prohibits "nuclear weapons or . . . other weapons of mass destruction" in Earth orbit or anywhere else in space (which is not legally defined).13/ Every strategic nuclear arms control accord since the SALT I ABM Treaty (Annex D) and Interim Agreement of 1972 frowns on interference with "national technical means of verification," which mainly comprise reconnaissance and surveillance satellites.14/ Future agree-ments might forbid various kinds of launch vehicles and/or facilities, space-to-earth offensive weaponry, and space-based homeland defense. Arms controllers alternatively could try to confine the range, power, speed, and deployment areas of certain space systems.

Representative applications, which could shape or prevent antisatellite (ASAT) development and deployment, are under active consideration. International law , for example, might proscribe mines that maneuver or possess standoff capabilities, and prescribe minimum distances between satellites. Trespass into resultant sanctuaries would be a hostile act. It would be impossible to perfect ASATs for use against maneuverable targets, while allegedly practicing space station linkups, if allowable rendezvous speeds were slow. Limitations on power output might make lasers useless for ASAT. Moratoriums that tolerate existing systems, but freeze ASAT technology (a practice often called "grandfathering"), would impede modernization. Suspension of ASAT tests would further impede future capabilities. Arms controllers, however, admit that freezing an inequitable balance could be destablizing and ambiguities might make some restrictions hard to monitor. Ballistic missile defense weapons designed to intercept small, high-speed targets, for example, could easily double as ASATs.15/

The face value of arms control objectives, including those identified with ASAT, is seldom obvious. Verification is critical. Space strategists therefore should look for underlying reasons before they become euphoric about apparent rival concessions. "If you don't pay attention to the periphery, the periphery changes, and the first thing you know, the periphery is the center," is the way former Secretary of State Dean Rusk once put it.

Control Terrain

Major military and civilian installations on the moon and in free space, associated facilities on Earth, selected orbits, and lunar libration points constitute critical terrain in the context of this study (see Chapter 1 for discussion). Control of features in those categories may sometimes seem preferable to arms control during periods of peace, if political, economic, and/or military power are predominant interests. Terrain control objectives almost invariably take precedence over arms control during combat.

Not all critical terrain in the Earth-Moon System, however, is equally advantageous. Present and potential values reflect many variables, including costs, risks, and time. Short- and long-term objectives may be dissimilar. Only one goal qualifies as the strategic center of gravity, "The hub of all power and movement, on which everything depends."16/

Lunar libration points L4 and L5 eventually may evolve as the strategic center of gravity if, as alleged, they prove to be the ultimate high ground. Meanwhile, C^3 and launch sites on this planet will clearly qualify well into the Twenty-First Century, because all military and civilian activities in space would cease without their support. Serious threats to such installations would more likely elicit sharp responses than any endeavors to control any critical terrain in space.

Control Attitudes

Lenin once wrote that "The soundest strategy is to postpone [military] operations until the moral disintegration of the enemy renders" a "mortal blow both possible and easy."17/ Many great minds before and after agreed.* National will to compete in space thus may comprise the strategic center of gravity during peacetime, and might retain that pinnacle position during any protracted war.

Control over elitist and popular opinion, using inexpensive psychological operations (psyop) as a non-lethal weapon system, could convince rivals that it is useless to start or continue military space programs. The basic objective would be to deprive opponents freedom of action, while preserving it for oneself.19/ Senior national executives, legislators, members of the mass media and, through them, the body politic would be typical targets. Representative psyop themes might include the futility of efforts to achieve military superiority in space, concomitant perils to world peace, and a waste of resources better spent on living standards than on a fruitless arms race.

THREAT INDICATIONS

Intelligence estimates that deal with the nature, imminence, and intensity of threats to security interests and objectives in space are particularly complicated, because many traditional indications are inapplicable. Present capabilities, projected capabilities, and intentions, pose special problems, in ascending order of difficulty. So do conclusions concerning resultant risks and opportunities. Space may prove to be a particularly fruitful environment for deception, because it is virgin territory.

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*Sun Tzu, in the first treatise on the art of war, circa 500 B.C., affirmed that "to subdue the enemy without fighting is the acme of skill." B.H. Liddell-Hart, one of Britain's most famous strategists, paraphrased that thought this way 25 centuries later: "The true aim is . . . to seek a strategic situation so advantageous that if it does not of itself produce the decision, its continuation by a battle is sure to achieve this".18/

ENEMY CAPABILITIES IN SPACE

Capacities to execute specific courses of action in space (deter, attack, defend) at specific times and places rest in large part on quantities, qualities, characteristics, and locations of forward deployed forces, plus components in reserve.

Present Capabilities

Ascertaining current capabilities is the simplest part of any threat appraisal. Attempts to assess existing strengths and weaknesses of enemy space forces nevertheless must lean extensively on subjective intelligence at this moment, because so little is objectively knowable.

The attributes of formations on land, at sea, or in the air are comparatively familiar. Weapons and equipment, with rare exceptions, are well observed during predeployment tests, training, and occasionally in combat. No layman is likely to confuse tanks with trucks or bombers with light observation aircraft. Command ships that bristle with antennae bear little resemblance to amphibious landing craft. Space systems, however, presently display fewer distinctive external features. Civilian vehicles can be used surreptitiously for military activities. Components as diverse as lasers, sensors, and telecommunication devices commonly are developed and tested separately, then marry inside covers that conceal composite purposes. Weapons, for example, may piggyback on satellites that are advertised as, or appear to be, purely for reconnaissance and surveillance.

Hard intelligence about enemy space capabilities thus is hard to acquire. Launch times and places, orbital paths, maneuver patterns, and flight durations frequently offer better clues to enemy capabilities than can be inferred from satellite configurations. Soviet communication satellites, for example, commonly occupy highly elliptical orbits that allow long loiter times over the northern hemesphere. U.S. equivalents prefer GEO. Telemetry, even encoded, may help rivals unravel secret purposes of the emanating source.20/

The finest intelligence analysts in this arcane field, like detectives forced to fall back on circumstantial evidence, must possess inquisitive minds, intellectual acuity, intuition, and tenacity. Geoffrey E. Perry, senior science master at Kettering Grammar School in England, personifies those traits. That amateur satellite tracker and his students have produced invaluable insights into Soviet space reconnaissance programs since 1962.21/

Projected Capabilities

Superiority in space could culminate in bloodless total victory, if lagging powers could neither cope nor catch up technologically. Lesser unilateral breakthroughs could reduce rival abilities to resist aggression on Earth and beyond in many significant ways.22/

Science and technology are twin keys to future space capabilities, but forecasters in those fields find it troublesome to predict the progress of friends, much less that of opponents whose exploratory programs are well concealed. Pundits who insist that any technological problem is insolvable have repeatedly proven wrong. Cracked crystal balls invariably overlook impending developments of great magnitude. Technological Trends and National Policy, a 1937 U.S. study, failed to foresee radar, jet engines, and nuclear weapons, which were operational within eight years or less. Dr. Vannevar Bush, Director of Scientific Research & Development, and the Von Karmann report entitled New Horizons both discounted ICBMs in 1945; Soviet tests took place in 1957. Skeptics in 1961 doubted men would soon land on the moon and return safely during that decade. They were mistaken.23/

Since surefire predictions perhaps are impossible, given the dearth of hard data, it is important to press states of art wherever technological surprise in or from space conceivably could alter the military balance decisively. Failure to do so would deprive decisionmakers of sufficient vision to determine what enemy capabilities are possible in any given time frame, separate possibilities from probabilities, and take appropriate action.

ENEMY INTENTIONS IN SPACE

The most dangerous capabilities become dangerous threats only if opponents intend to employ them at specific times and places. Interests, objectives, policies, principles, commitments, and national will are determinants.

Some elemental intentions in space are easily discernable. The appearance of large military bases and mobile stations clearly would signify determination to establish a permanent manned presence and open options. Beyond basics, however, intelligence analysts find that space operations magnify uncertainties in the estimative process.

Some signs of impending enemy attack, such as political crises, intensified reconnaissance/surveillance, sudden cessation of communications, and increased message traffic from control centers to potential assault forces, apply equally well to land, sea, air and space. Occupation of standby bases and forward movement of reserve forces, transportation, and supplies may be among them. Many traditional intelligence indications, however, seem immaterial, even irrelevant (NATO's watchlist exceeds 700, according to the last public count). Mobilization, large-scale leave cancellations, mass stand-downs for maintenance, and arrival of personnel fillers that bring combat forces to full strength, for example, may never be important omens of impending space combat.24/

Distinctive indicators that foretell enemy Earth-to-space, space-to-Earth, and space-to-space offensives therefore are in demand. Tip-offs could include such disparate factors as the inexplicable deployment of additional spacecraft peculiarly adapted for offensive armed conflict; the assembly near launch sites of spare enemy payloads and boosters perhaps intended to replenish combat losses in space; and orbital alterations that might embellish enemy abilities to strike particular targets on Earth or in space. Directed energy weapons (lasers, particle beams), which propagate at the speed of light, put a premium on strategic warning,* since tactical warning after they attack may at most be measured in milliseconds. Eternal vigilance might not ensure survival, if DEWs proliferate. Arms control thus seems advisable.

MILITARY STRATEGIES, OPERATIONS, AND TACTICS IN SPACE

High commands design military strategies to attain national and regional security objectives, despite perceived threats. Major combatant commands, which specialize in operational art, prepare supporting plans that put strategic concepts into practice. They conduct military campaigns, if armed conflict occurs. Subordinate forces employ techniques called tactics to implement strategies and operational plans in detail during battles and lesser engagements.25/

Military space planners, whose province is unlike land, sea, and air, need to develop new theories, concepts, assumtions, and options in three categories: attack, deterrence, and defense. Full discussion is beyond the scope of this study. The following briefs simply illustrate the breadth, depth, and complexity of short-, mid-, and long-range problems that await sound solutions.

PLANNING ASSUMPTIONS

The time, place, type, scope, intensity, and duration of threats that endanger national security interests and objectives are hard to predict. Assumptions, presumed correct in the absence of contrary proof, fill current information gaps and replace facts concerning the future. Military space planners must rely more on assumptions than Earthbound counterparts, who deal with familiar mediums.

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* Strategic warning may be received minutes, hours, days, or longer before opponents attack. Tactical warning may be received any time from the moment attack commences until first effects are felt.

Many assumptions apply equally to Earth and space. War, for example, is probable or implausible; warning times will be short or long; armed conflict will be high-, mid-, or low-intensity, nuclear or conventional, volitionally limited or boundless, brief or prolonged.26/ Space-specific assumptions with profound implications might include:

- Superpowers will (not) pose the only serious threats in space for the next 25-50 years.
- Space colonies and competition for lunar resources will (not) cause armed conflict.
- Space warfare can (not) exist in isolation from conflicts on this planet.
- Military superiority in space would (not) confer decisive advantage.
- Lunar libration points L4 and L5 do (not) militarily dominate the Earth-Moon System.
- Deterrence in space does (not) depend on survivable space-based systems.
- Offense will (not) dominate space operations for the foreseeable future.
- Special operations will (not) become significant factors in space.
- A mix of manned and unmanned military spacecraft is (not) imperative.
- Technological breakthroughs will (not) revolutionize space warfare within 25-50 years. By the year 2025, for example:
    - Orbital mechanics will (not) severely impede Earth-to-space and space-to-Earth operations.
    - Atmosphere will (not) severely impede Earth-to-space operations.
    - Radically new forms of power and propulsion will (not) be commonplace in space.
- Resources, and the will to employ them, are (not) and will (not) remain sufficient to satisfy national security interests in space during the next 25-50 years.

Space planners and overseers on Capital Hill could double or triple the foregoing political, economic, military, technological, and geographic assumptions in a few minutes, without padding the list.

ATTACK OPTIONS

Sun Tzu probably overstated his case when he wrote, "Invincibility lies in defense; the possibility of victory in attack,"27/ because "victory" can be variously defined. Defenders who deny foes success, protect themselves at acceptable cost, and accomplish other negative aims "win" as much as they want. They must attack, however, to seize hostile territory, control most enemy activities, or achieve other positive objectives.

Perhaps more importantly, present trends indicate that offensive forces soon may dominate space much like nuclear weapons outclass countermeasures on this planet, and retain marked advantage until much better defenses emerge.28/ If so, countries and coalitions that lack strong offensive (or counteroffensive) capabilities in space could forfeit freedom of action and find it difficult to deter armed aggression against their interests anywhere.

Strategies, operational art, and tactics emphasize options. Uniservice, joint, and collective security doctrines prescribe standard procedures under specified conditions. Military space planners, who must blend those seemingly irreconcilable qualities in their quest for sufficient offensive capabilities, make dominant decisions concerning mission priorities, target preference, and weapons.

Mission Priorities

The Principle of War called "Mass" sends an important message: concentrate strength on vital objectives, economize elsewhere. Air power proponents, who grasp the full significance of that notion, long ago assigned top priority to air superiority, because strategic bombing, battlefield interdiction, close air support, reconnaissance, transportation, and command/control missions are difficult or infeasible if rivals rule the air.29/ Strategists now should ascertain whether analogous needs exist in space, where reconnaissance/surveillance and homeland defense currently compete for first place. Forces deployed for those purposes, however, could not survive long in hostile environments where opponents hold the upper hand. Mission priorities thus may be misplaced.

Target Preference

The desirability of attacking any given target depends on variables that include objectives, perceived threats to their accomplishment, degrees of difficulty, escalatory limitations, unwelcome side effects, and costs to attack. Troublesome trade-offs arise when key considerations conflict.

Criticality and Constraints

Elaborate facilities to launch and control space vehicles from Earth will be strategically attractive targets far into the future. They are scarce, vulnerable, indispensable, and irreplaceable. Complementary installations eventually may appear on the moon, and perhaps in free space. Destruction or protracted disruption might immediately and decisively alter military balances on a grand scale. Enemy space-based interceptors and active defenses in position to interfere constitute high priority tactical targets. Naval surface ships comprise a third inviting target category that may be strategic or tactical. Former astronaut Michael Collins, who has been there and back twice, believes space is an ideal place from which to attack aircraft carriers and other major surface combatants, which are expensive and slow; even 100-knot hydrofoils would be easy for satellites to track, because ships "stand out as clearly as billiard balls on green felt."30/

Latitude for striking such targets is greatest during high intensity conflicts, when few holds are barred, but hard choices nevertheless will crop up in situations short of total war. Unwanted escalation, for example, could follow attacks on space facilities in the enemy homeland, even if collateral damage were strictly confined.31/ Leaders who strive to provide space support for their own land, sea, and air forces, deny space support to opponents, and simultaneously avoid adverse effects during low- and mid-intensity conflicts likely will declare many lucrative targets off limits. Representative targets in the left hand column of the short list below as a general rule risk greater escalation than those on the right:32/

L4 and L5
Lunar Garrisons
Manned Space Stations
Battle Management Satellites

Space Mines
Spares Stored in Space
Unmanned Satellites
Antisatellites

Inconstancies and Costs

Photoreconnaissance satellites illustrate how target values may vary with situations. Those positioned to collect strategically important basic intelligence in peacetime pose no immediate threat. Identical satellites positioned to provide pictures that help direct wartime operations on Earth or in space comprise present dangers. Satellites able to accomplish both missions without altering orbits are comparatively benign before war begins, but become lethal weapon systems thereafter.33/

There rarely is any requirement to damage, destroy, or otherwise interdict every component in high priority target complexes. Surgical strikes against communications switching centers and relay satellites, for example, would be quicker and more cost-effective than saturation attacks on an entire ballistic missile defense constellation, unless its components operate autonomously. Life support systems will always be weak spots in space colonies and major military installations on the moon.34/

Costs to attack some targets on Earth with space-based weapons probably will be prohibitive until far in the future (perhaps forever). High-resolution satellite sensors currently can see inside foxholes on cloud-free days. They can spot individual armored vehicles and aircraft. Not many commanders, however, would expend high-priced orbital ordinance on such low value targets. Airborne Warning and Control System (AWACS) aircraft and nuclear strike forces might be prominent exceptions.35/

Weapon Preference

Planners must pick the most appropriate arms from a diversified arsenal. Mass destruction and precision instruments compete for attention. Directed energy weapons (DEW) and some types of radiation attack at the speed of light. Space mines move sluggishly in comparison. Spoofing normally is a nonlethal option, but might misdirect space weapons against friendly forces.36/ Target accessibility and survivability, concerns for escalation, and damage desired strongly influence decisions to engage any point or area target with particular weapons (see Chapter 1 for selected nuclear, directed energy, chemical, and conventional weapon effects in space).

Hard Kill Weapons

"Hard kill" weapons forcibly break the surface of targets, then damage or destroy their contents. Violence is evident to observers. Explosives and kinetic projectiles are representative instruments.

Nuclear warheads are the most escalatory of all area weapons. Space-to-surface and surface-to-surface shots that detonate on Earth or in its atmosphere would be equally lethal, but space-to-surface delivery currently is (may always be) more costly, less accurate, and tougher to control. Nuclear hard kill capabilities would seldom be cost-effective against targets in space, because vacuum restricts blast and heat radii so severely that conventional explosives and kinetic energy weapons can accomplish most missions equally well at less expense. Soft kill nuclear radiation, unimpeded by atmosphere, conversely could cover orders of magnitude more volume than near Earth's nap. It would work especially well against suspected targets in low earth orbit (LEO), but less consistently in deep space, unless targets were located more accurately, since the lethal range of radiation is limited, even in a vacuum. Nuclear radiation in any event suffers one great disadvantage: it cannot distinguish friend from foe. Electromagnetic pulse, for example, might "wound" users as grievously or worse than intended victims.37/

Conventional explosives and kinetic energy weapons (KEWs) are designed exclusively for hard kills. Proper employment in space depends extensively on precise targeting intelligence, plus "smart" (even "brilliant") munitions. Direct hits are almost obligatory for conventional explosives, because vacuum cancels the concussive effects that make many near misses deadly on Earth. The tolerable margin of delivery error also is small for KEWs, even "shotgun" styles that scatter pellets in the orbital paths of speeding targets. Offensive KEWs plummeting from space-to-Earth at Mach 12 or more with terrific penetration power have a marked advantage over defensive Earth-to-space counterparts that accelerate slowly while they fight to overcome gravity. Simple weapons associated with sabotage and other special operations open low key hard kill offensive options for use against space installations anywhere in the Earth-Moon System.38/

Speed-of-light directed energy weapons (DEW) likely will be preferred implements whenever space-to-space attackers try to take point targets by surprise. Weapon quality lasers and particle beams await substantial technological breakthroughs, however, before they can operate successfully across the boundary between atmosphere and space. Space-toward-Earth capabilities against targets in rarified atmosphere are simplest to perfect. Space-to-Earth DEW operations are much farther in the future, because dense air is more difficult to penetrate and targets ashore or afloat on the surface are easier to shield. R&D specialists anticipate Earth-to-space DEWs at an earlier date, since large power supplies are more readily attainable on terra firma than on spacecraft and most targets in space will always be relatively soft. One undesirable attribute merits mention: the source of super fast laser attacks that bounce off space-based reflectors may be untraceable. Catalytic conflicts* and retaliation against wrong parties could result. Space strategists concerned with unplanned escalation and other unwanted contingencies should consider such possibilities, and employ DEWs cautiously.39/

Soft Kill Weapons

"Soft kill" weapons penetrate target surfaces without impairing them, then selectively disorient, damage, or destroy humans and/or sensitive mechanisms inside. Electronic countermeasures and nuclear radiation are representative instruments.

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*Catalytic conflicts are armed combat between two countries or coalitions that a third party instigates deliberately. Suspicion, for example, almost spontaneously would point toward an innocent Soviet Union, if a third nation bombarded the United STates with SLBMs during a U.S.-Soviet crisis. Opportunities for mischief will multiply after several countries deploy DEWs in space.

Soft kills generally cost less and escalate conflict less than hard kills. Jamming, which reduces communication data rates or renders signals unintelligible, requires complex techniques and sophisticated equipment. Other potential methods are simple. Spray paint on satellite camera lenses, blinding light on laser reflectors, and surreptitious introduction of foreign objects into booster fuel are typical possibilities. False commands and other forms of "spoofing" may cause enemy satellites to malfunction. Victims who suspect foul play are hard pressed to prove it, if opponents are clever.40/

Attack Techniques

Armed forces in space, as on Earth, must concentrate physical presence or firepower to defeat enemies. Simultaneous assaults to decrease warning times and/or increase shock effects on widely separated targets, however, are tricky propositions, particularly when weapons have dissimilar characteristics and firing points are far apart. Directed energy weapons promise to simplify, but cannot solve, such problems. Opportune maneuvers, coupled with surprise and deception, always will be important.

Offensive Maneuvers

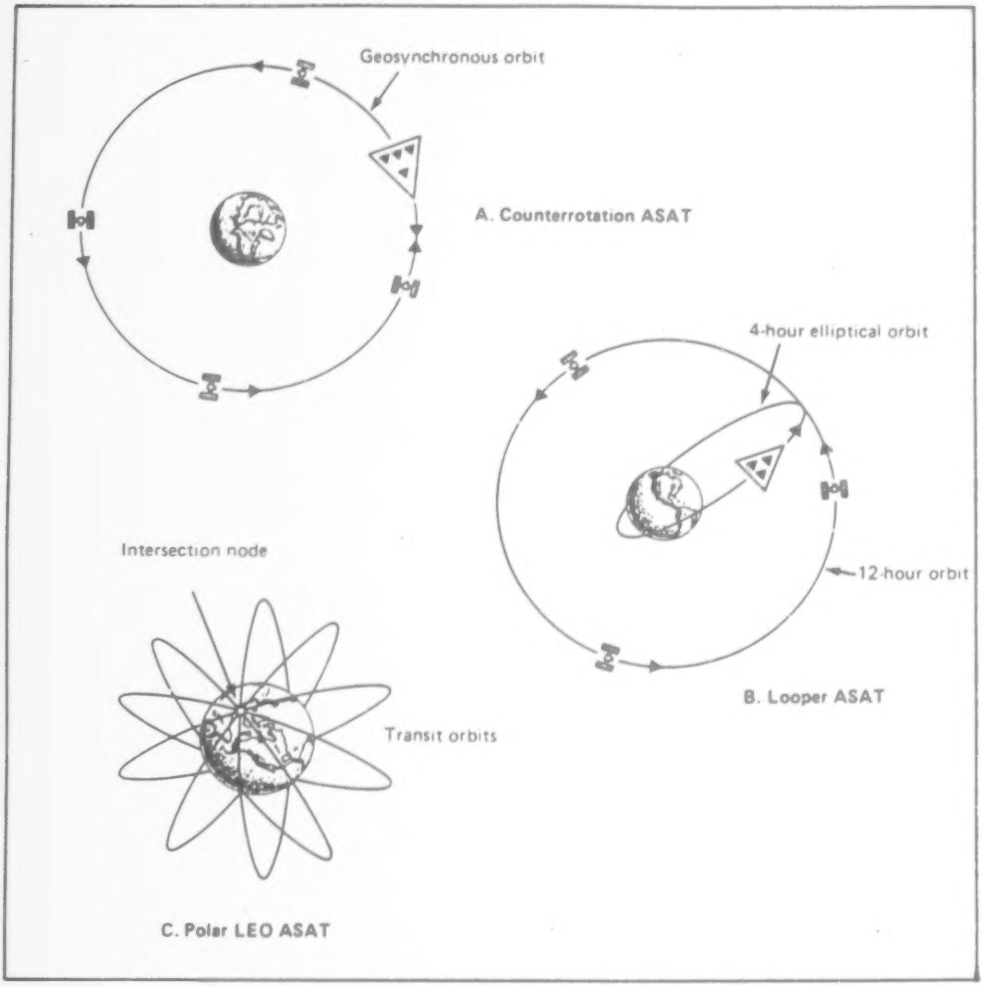
Strike forces on the moon could choose from the full range of offensive maneuvers in vogue on Earth. Broad-based frontal assaults and narrow penetrations, both of which meet the enemy head-on, would be least imaginative, and useful mainly against clearly inferior opposition. Envelopments from above or against flanks and turning movements that bypass forward defenses to attack the rear would need fewer assets to achieve superior results. Clandestine infiltration of hostile positions completes the list of potential lunar maneuvers.41/

Free space is different. Front, flanks, top, bottom, and rear there depend more on the direction orbiting sensors and weapons face than on the direction of flight. Peacetime infiltration, which could put attacking forces in decisive positions before or during crises, need not be clandestine, since space, like international waters, is no nation's preserve. Complex enemy space formations called "constellations" may make axes of attack immaterial, because widely separated satellites point sensors and weapons omnidirectionally. Strategic and tactical maneuvers moreover may be dissimilar. Flank attacks on individual targets, for example, might be a frontal assault on an enemy constellation.

Orbital mechanics and human ingenuity are the main limitations on maneuvers in space (see Map 10 for three imaginative possibilities). Offensive armaments that engage high velocity orbital targets at sharp angles must solve formidable problems. Counterrotation ASATs that attack almost head-on *(Map 10)* must follow tracks slightly different than those of their targets or collide. Long leads and superlative homing devices are essential at

MAP 10
SELECTED ANTISATELLITE ORBITS

Not to scale



A. Counterrotation ASAT traverses GEO in "wrong" direction. Attacks all enemy satellites there in 12 hours.

B. Three enemy satellites are in semisynchronous orbit 4 hours apart. Looper ASAT picks off each one as it passes the intercept point.

C. Battery of ASATs at North Pole take less than 2 hours to destroy all enemy satellites in polar LEO.

NOTE: Adapted from Carter, Ashton B., "Satellites and Anti-Satellites," International Security, Spring 1986, p. 83.

extended ranges for all but speed-of-light weapons*. Accuracy is easily attained by systems that coorbit with targets at close range, but they forfeit any possibility of strategic surprise. 42/

Surprise and Deception

Surprise does not vouchsafe success, but it vastly improves the odds and frequently is decisive. Complete surprise catches foes flatfooted. Partial surprise conceals the significance of activities long enough to reduce or forestall effective defense.

Speed (typified by directed energy weapons that strike without warning) and audacity (you can get away with almost anything once) can contribute to surprise. Earth-to-GEO (and much of MEO) ASATs probably always will forfeit surprise, because they would be easily observable during flights that take hours, given any technology now foreseen. Space mines, conversely, would be in constant position to pounce. Bombardment anywhere in the Earth-Moon System from bases floating far beyond GEO might well avoid early detection, particularly if missile burn times were brief.43/

Prototype strategist Sun Tzu professed that all warfare is based on deception, which muddles fact with fiction.44/ Deception indeed might abet surprise in space, even though sensors can spot potential enemies at great distances in every direction. Vacuum makes it hard to discriminate between heavy missile warheads and lightweight decoys, which flutter in telltale fashion when they enter the atmosphere. Spoofers in space, like those on this planet, would find it easy to flood rival receivers with deceitful messages; recipients would find it hard to separate bogus from bona fide traffic. Civilian "fronts" for military space activities likely will become more common. Prewar proof of fraudulence will be elusive. Camuflage specialists face formidable problems. Offensive satellites that simulate meteoroids or space debris, for example, would scarcely fool sentinels that watched them arrive from Earth or moon; surreptitions insertions from HEO to GEO or LEO, however, would be more difficult to detect. Fakers, however, might choose a different tack when camouflage is infeasible. One possibility: deploy falsely advertised, widely dispersed space weapon components, then assemble them unexpectedly.

Deception is risky business in any case, because failures can backfire disastrously. Planners who pioneer techniques in space must be even more imaginative than Earthbound counterparts.

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*Even DEWs must lead distant targets, which they identify by infrared or reflected light. Spacecraft 1,800 miles away, for example, would move 50-100 yards or more in the 0.01 second it would take for reflections to reach the weapon, and another 50-100 yards before a laser beam could return.

DETERRENT OPTIONS

Attacks never take place, if deterrent powers are sufficient.45/ "Sufficiency" nevertheless is hard to define, partly because planners never can prove what worked, partly because they must counter many possible causes of war that include (but are not confined to) uncontrolled crises; justifiable confidence in favorable outcomes; overconfidence; other miscalculations, such as fallible brinkmanship; unacceptable provocations; accidents; and catalysis (conflict triggered by third parties). Deterrent postures that alleviate one cause may aggravate others.46/

Preparedness and Nonprovocation are Principles of Deterrence.47/ Those yardsticks give some feeling for the scope and perplexity of problems that military space policymakers face, as they seek the best balance between desirable and undesirable features.

Preparedness

Nothing encourages aggressors more than opponents with their guards down. Preparedness consequently is one price of peace. Deterrent architects, however, cannot even get started until they answer the question: Prepare to do what?

Preparation to surge space deployments on short notice in response to severe provocation purportedly could strengthen deterrence, by demonstrating readiness and resolve. Some committed forces already in space might move swiftly to more favorable stations. Standby elements on the moon and/or in orbits also could augment "forward deployments" rapidly. Reinforcements from Earth would take a little longer, but lags would be acceptable, unless strategic warning times were short.48/ Decisions to surge nevertheless are dicey, unless enemy response is reasonably predictable. A sudden military buildup in space might precipitate the attack it sought to discourage, if deterees believed the deterrer was about to preempt.

Readiness to reciprocate in kind is another deterrent notion, an eye for an eye, a tooth for a tooth: assault my spacecraft, I assault yours. Anti-satellite capabilities pose a powerful disincentive, according to that concept, provided adversaries are vulnerable, cannot replenish losses quickly at acceptable cost, and want to preserve their own vehicles more than they want to inconvenience rivals. Some critics, however, question the need for ASAT-induced deterrence, because aggression against space systems could have adverse consequences beyond anticipation. Others insist that threats to retaliate against maritime or terrestrial targets could discourage attacks on spacecraft as well or better than ASAT, despite countercontentions that doing so might elicit unwelcome escalation, and thus degrade deterrence. Careful thought consequently should precede any decision to accept or reject ASAT for deterrent purposes.49/

Catch-22 conundrums, however, do not justify protracted indecision. Space policymakers who delay preparedness despite evident peril may jeopardize deterrence, if enemy leaders interpret inactivity as lack of will and act accordingly.50/

Nonprovocation

Preventive and preemptive wars erupt when real or imagined provocations convince aggrieved parties that a shootout is inevitable sooner or later.* They have little to lose and maybe something to gain by striking first. Successful deterrent strategies must dampen such proclivities, which is no mean task, since "provocations" are subjective matters.

Space-based defenses designed to deter ballisitc missile attacks, for example, may seem innocuous to installers, but pernicious to opponents, because any nation unilaterally able to neutralize most enemy nuclear-tipped missiles in flight could secretly harbor first strike ambitions. Armed with a few offensive weapons, it might in fact win without fighting (the ultimate achievement), then direct losers to disarm. Poorly shielded foes would face two unattractive alternatives: surrender or suicide.51/ Dividing lines between deterrence and destabilization thus are indistinct. Planners who try to draw them sharply could trigger the trouble they hope to avoid.

Risk reduction measures, much like those now designed to forestall nuclear conflict on Earth, might promote deterrence equally well in space. Routine discussions between suspicious protagonists; crisis consultations, including high-level "hot line" conversations; advance explanation of potentially disturbing operations (large maneuvers, major relocations); and on-site inspections of launch sites, satellites, space stations, and lunar installations typify potentially helpful confidence-building techniques. Prudence, however, is imperative, because revelations could devitalize deterrence predicated on uncertainty. Planners also must guard against false impressions derived from enemy deception and disinformation.52/

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*Degrees of premeditation differentiate preventive and preemptive wars. Deliberate preparation precedes the former. Threatened parties preempt on short notice to attenuate the effects of imminent enemy attack.

DEFENSE OPTIONS

Defense bolsters deterrence, by denying aggressors a free ride.* It also reduces dangers, if deterrence fails. What, where, and how to defend are fundamental policy decisions.53/

Five factors help planners determine which assets on Earth, its moon, and in orbit would benefit most from defense:

-- Relative target value
-- Relative target vulnerability
-- Relative likelihood each target will be attacked
-- Relative time each target must survive
-- Reconstitution times

Many factors that include missions and financial costs determine target values. Enemy capabilities determine the relative vulnerability of each target. Intelligence estimates indicate which ones most likely will be attacked in what sequence. The time each target must survive depends on its purpose. Trained manpower and materiel reserves, standby delivery systems, production schedules, and construction capacities determine reconstitution times.

Space strategists and tacticians use those five factors to put defense problems in priority, then devise schemes to reduce detection by enemy sensors, defeat attacks by enemy units, and reduce damage to targets that are hit.

Active and passive defenses listed in the left hand column of *Figure 3* are complementary. A few options are applicable only on Earth and moon or in free space, but several serve well in all environments. Some have limited utility, others are universally convenient. Proper mixes are complicated matters. Many trade-offs, for example, not only increase costs, but decrease spacecraft capabilities, because they add weight, exclude preferred deployment patterns, and complicate control.

Reduce Detection

The world's best offensive space weapons would be worthless, if wielders were unable to locate targets accurately and identify their functions. The first line of defense, in peacetime as well as war. therefore is to frustrate enemy reconnaissance and surveillance efforts.

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*Some deterrent concepts, such as Assured Destruction, scorn defense. Assured Survival advocates find defense indispensable (insecure forces, they contend, tempt rivals to preempt). Compromise positions separate those polarized positions.

Figure 3

DEFENSE AND DAMAGE LIMITING OPTIONS

	REDUCE DETECTION BY ENEMY SENSORS			DEFEAT ATTACKS IF DETECTED				REDUCE DAMAGE FROM ENEMY WEAPONS					
	OPTICAL	ELECTRONIC	INFRARED	DIRECT ATTACK		STANDOFF ATTACK		HARD KILL WEAPONS			SOFT KILL WEAPONS		
				ASSAULT	SABOTAGE	CLOSE RANGE	LONG RANGE	DEW	KEW	EXPLOSIVES	EMP	ECM	SPOOF
UNIQUE OPTIONS, EARTH & MOON													
Concealment	X		X										
Isolation1/	X	X	X	X			X						
Mobility	X	X	X				X						
Natural Cover	X		X	X		X	X	X	X	X	X	X	
Restricted Areas1/	X			X	X	X							
Security Forces1/	X	X	X	X	X	X							
UNIQUE OPTIONS, ORBITING SPACECRAFT													
Autonomy2/								X	X	X	X	X	
Elusive Orbits	X	X	X				X						
Isolation1/	X	X		X									
Maneuver				X			X	X					
Restricted Areas1/				X	X	X							
Security Forces1/				X	X	X							
Short-lived Craft 2/								X	X	X	X	X	
Single Mission Craft2/								X	X	X	X	X	
Space Mines				X	X	X							
Unmanned Craft2/								X	X	X			
UBIQUITOUS OPTIONS													
Deception	X	X	X	X	X	X	X						X
EMF Frequencies											X	X	
Encryption													X
Hardening	X	X	X	X	X	X	X	X	X	X	X	X	
Interceptors	X	X	X	X		X	X						
Reconstitution2/								X	X	X	X	X	
Redundancy2/								X	X	X	X	X	
Stealth	X	X	X										

1/ Not entirely unique to Earth and moon or to spacecraft; one or more attributes are dual purpose.

2/ Option does not reduce damage from enemy weapons, but reduces adverse results.

GENERAL NOTE: See Annex A (Glossary) for precise definitions.

Targets on Earth and Moon

Large space support installations and other high value static targets on Earth and moon may be impossible to veil very long. Defenders, however, can make it difficult for opponents to pinpoint key components and catalog activities. Cover and concealment help hide targets from optical, electronic, and infrared sensors. Geographic isolation, restricted areas, and local security forces do little to foil airborne and space-based finders, but reduce surface observation (such measures, for example, effectively screened facilities at Los Alamos and Alamogordo, New Mexico, where final development of the first atom bomb and its open air test took place in complete secrecy). It currently is possible to move some targets temporarily out of view when surveillance satellites pass overhead, but that option will disappear when spies crowd the skies. Defenders could reduce rival detection capabilities most decisively by intercepting snoopers. Such action during peacetime crises, however, would be risky.

Targets in Space

Procedures to prevent detection of targets in transparent space are different. Natural cover and concealment (other than isolation) are nonexistent. Restricted areas and security forces are irrelevant. Defensive deception has serious drawbacks, like those described in the section on attack techniques.

Nevertheless, some targets are hard to detect. Systems orbiting in deep space are like needles in haystacks. Elusive orbits help defenders escape detection. GEO, for example, is beyond the range of most Earth-based radars. Weather and lighting conditions restrict optical tracking.54/

Stealthy technology, which honors the adage, "lose sight, lose the fight," seeks to obscure spacecraft in flight by combining sleek contours with non-metallic materials, absorptive coatings, heat shields, emission controls, passive guidance, and countermeasures that muffle or falsify enemy sensor returns. Several advanced composites blot radar beams better than any alloy. Optically transparent compounds blend with natural light in ways that render reflecting surfaces virtually invisible. The cycle of innovation, neutralization, and renovation has just started.55/

Stealthy spacecraft in some respects will be easier to create than will-o-the-wisp aircraft and cruise missiles.56/ Hard-to-conceal external stabilizers are unnecessary in the vacuum of space. Hi-lo-hi flight profiles never subject external materials to great stress, unless orbits dip deeply into the atmosphere. Engine emissions are momentary and intermittent. Pluses and minuses nevertheless mix. Space vehicles that launch under enemy surveillance are easier to track than aircraft, because most must fly predictable paths at predictable speeds. Attempts to conceal locations thus might be impossible, unless accompanied by "delousing" stratagems like those that let submarines slip out of port undetected. Solar power panels, which will be popular until a better replacement appears, are difficult to camouflage. Large space stations may some day enjoy closed ecologies, but other spacecraft must dump easily detected waste and heat to avoid intolerably high temperatures and insanitation.

Defeat Attacks

Offensive forces certainly will detect and identify many high value targets, despite clever countervailing. The second line of defense therefore is to deflect or defeat attacks.

Passive defense includes all protective measures short of armed force in any form. Active defense features weapon systems. Defensive maneuvers on the moon will be much different than those in free space.

Passive Defense

Many passive defenses that perform well on Earth would also work well in free space. Deception, hardening, mobility, restricted areas, electronic countermeasures (ECM), and counter-countermeasures (ECCM) are typical (Figure 3). All would apply on the moon, where shelters could include topographic features and man-made fortifications, for which lunar construction materials are abundant and readily available. Subterranean installations, impervious to all but burrowing nuclear weapons, seem feasible.

Launch/recovery sites, C^3 installations, production bases, support facilities, and other Earthbound infrastructure for space operations may be vulnerable to attacks from land, sea, and air, as well as space. Assets positioned far from hostile frontiers and ocean shores are least accessible to conventional armed forces. Isolation, however, does less to reduce dangers from saboteurs. Local security precautions could include strict counterintelligence checks, bare perimeters around hard-to-breach buildings, obstacles, guard posts, roving patrols, anti-intrusion devices, other sensors, and convoy "shotguns."57/

Defensive Maneuvers

Positional defenders on the moon, much like those on Earth, could employ small elements well beyond the main body to distract and disrupt enemy thrusts from front, flanks, top, and rear, then counterattack. Mobile defenses, conversely, could rely on light forces to hold selected strong points. Large, agile reserves deployed in great depth could strike back when invaders become most vulnerable. Retrograde maneuvers would be feasible, if those forms of defense fail. Units leapfrog from one delaying position to another in the rear; break contact and withdraw; or retire before they make contact.58/

Defensive maneuvers in free space allow decisionmakers less discretion. Incentives to opt for positional defense will be few compared with Earth and moon, because little territory is intrinsically valuable enough to retain (lunar libration points, large space stations, and irreplaceable C^3 locations along GEO may be prominent exceptions). Delaying actions likely will be uncommon, since the scarcity of geographic obstacles makes most sites equally hard to defend. Forces well-shielded against radiation might fall back on the Van Allen Belts, if opponents were poorly protected against radiation, but would remain vulnerable to standoff weapons and might be unable to accomplish assigned missions from that location. The term "contact", in context with withdrawals and retirements, must be redefined and concepts redescribed to address interactions between defensive space forces many miles apart. One military space specialist suggests the following definitions:59/

Contact:	within sensor range
Engagement:	within weapon range and exchanging fire
Withdrawal:	move beyond enemy weapon range
Retirement:	move beyond enemy sensor range

The cost of maneuvering spaceships to escape interception varies from cheap to expensive. No significant penalties, for example, would accompany slight phasing irregularities that frustrate "looper" attacks (see Map 10). Automated frequency hopping, another frugal form of maneuver, could give enemy jammers fits. Evasive actions that substanically alter spacecraft orbits, however, exact a price in propellant, reduce payloads, and perhaps interrupt important missions at inopportune times.60/

Active Defense

Active defenses identified in Figure 3 fit two broad categories: surface-to-space and space-to-space interceptors; close-in and on-site security forces.

Nuclear-tipped missiles that transit space currently threaten targets on Earth. Voluminous studies, especially those associated with U.S. strategic defense initiatives (SDI), address various means of active defense, which center on KEW, DEW, and nuclear interceptors.61/ Policymakers must make elemental decisions, of which the following are representative: proportionate contributions of land, sea, air, and space components; proportionate contributions of point and area defenses; relative roles of active and passive security, including civil defense; how far forward to defend; how much to deploy in what time frame; the proper role of arms control.

Unclassified literature contains few references to defensive satellites (DSATs) or anti-ASATs. Almost all concern orbital interceptors of some sort, perhaps equipped with long-range weapons. Other modes, however, may prove more cost-effective under certain conditions. Shipboard DSATs might be among them, since any satellite killer launched in any direction from any location on Earth must pass over a predictable point on the opposite side of the globe half way through its first orbit. Those points, it so happens, almost all are over some ocean, and will remain so as long as most ASATs launch from land.62/

Active defense against direct assaults and special operations in space demands different techniques. Space mine fields might delay, disorganize, and channelize final approaches to targets in ways that make offensive spacecraft more vulnerable to other defensive weapons. Local security forces and booby traps could repel boarding parties.63/

Rules of engagement should specify limitations that pertain when defenders initiate, conduct, and terminate military operations to, from, and through space under given circumstances during peacetime, transition periods, and war. Commanders, to cite one typical case, need to know how far they should let unidentified or suspicious space vehicles penetrate restricted areas at what speeds before particular responses are permissible. Tailormade guidelines are required, because many variables influence minimum allowable distances and maximum closure rates. Violators, target values, the range and reliability of defensive weapon systems, reaction times, and environmental factors (such as atmosphere and gravity) are cogent considerations. Rules of engagement designed to protect reconnaissance satellites in LEO, for example, will bear little resemblance to those that affect scientific research stations in translunar space.64/

Reduce Damage

Deterrence and defense rarely safeguard targets completely. Damage limiting endeavors accordingly are advisable. Figure 3 displays two complementary types: one reduces the destructive power of enemy weapons; the other reduces disruption after successful enemy attacks.

Limit Destruction

Large space support facilities on Earth and moon will always be costly to protect against hard kill weapons and coverage likely will be incomplete. Segments buried in bedrock would be safest from high yield nuclear bursts. Critical components on the surface, however, remain exposed to sabotage and standoff attacks. Thin-skinned space vehicles, like aircraft and cruise missiles, are vulnerable to destruction by DEWs, KEWs, and explosives, whether parked or in flight. Exotic materials eventually may shield craft and occupants better than the best composites do today. Even slight wiggling motions could diffuse particle beams, which unlike laser burns easily penetrate the hardest shells.65/ Survivability nevertheless will be poor, until technologists and tacticians devise hard kill damage limitation measures much better than those now known.

The outlook for soft kill damage reduction is more favorable, but costs of security for space-related C^3 and other electronic systems vary considerably. Encryption and deception, which could virtually nullify enemy attempts to spoof, are least expensive. Extremely High Frequencies (EHF) could reduce nuclear scintillation and absorption from minutes to seconds. EHF also narrows transmission beams, so that enemy jammers must almost be in the line-of-sight between transmitter and receiver. Outlays for hi-tech hardware, however, would be large. Higher price tags would accompany programs to cope with electromagnetic pulse induced by large nuclear detonations in space. The acquisition, installation, operation, and maintenance of Faraday cages, filters, surge arresters, waveguide cutoffs, fiber optic links, and other sophisticated new devices would simply be step one. Retrofits for existing civilian and military sites would also be required.66/

Limit Debilitation

Steps to limit debilitation are desirable, because enemy weapons are sure to damage or destroy some intended targets, despite defensive efforts, unless the offense is very weak.

One way is to reduce relative target values. Many simple, single-mission, unmanned spacecraft designed to fly for short periods could do so. Individual losses would undercut the owner's overall capabilities a lot less than casualties among a few expensive, multipurpose counterparts with long-duration tasks. Largely autonomous space vehicles, able to perform most functions well without external instructions or support, would make C^3 centers on Earth and moon less lucrative aiming points, especially if cross-link communications let satellites bypass them easily.67/

Redundant deployments and reconstitution capabilities could also make damage more bearable. The former furnishes immediately available backup. The latter facilitates short-notice surges, permits tit-for-tat tactics that otherwise would be unattractive, and simplifies replacement. Proliferation and replenishment costs for space installations and systems, however, are literally astronomical. Large control centers, launch facilities, and space stations may always be impractical to duplicate and impossible to restore rapidly. Active and passive defenses able to keep damage within tolerable limits therefore are imperative.68/

Comparative Versatility and Value

Some defensive options described above are much more versatile than others, as *Figure 4* indicates. Versatility and value, however, do not always correlate closely. Hardening is most versatile, but high costs and unhappy tradeoffs between survivability and capabilities confine its usefulness in many important respects. Encryption, the least versatile entry in any category,

Figure 4

DEFENSE AND DAMAGE LIMITING OPTIONS
Relative Versatility

	MULTIPURPOSE	DUAL PURPOSE	UNIPURPOSE
Reduce Detection, Defeat Attacks, Reduce Damage			
Hardening	x		
Natural Cover	x		
Deception	x		
Reduce Detection Defeat Attacks			
Interceptors	x	x	
Security Forces1/	x	x	
Isolation1/	x	x	
Elusive Orbits	x	x	
Mobility	x	x	
Restricted Areas1/	x	x	
Defeat Attacks Reduce Damage			
Maneuver	x	x	
Reduce Detection			
Stealth	x	x	x
Concealment	x	x	x
Defeat Attacks2/			
Restricted Areas	x	x	x
Security Forces	x	x	x
Mines	x	x	x
Reduce Damage			
Autonomy	x	x	x
Short-lived Craft	x	x	x
Single-mission Craft	x	x	x
EHF Frequencies	x	x	x
Encryption	x	x	x

1/ Earth and moon only

2/ Space only

GENERAL NOTE: Options with the greatest versatility in each category along the left hand margin are listed first. The least versatile are last.

conversely is valuable, because it is the best way to defend against spoofing and denies enemy forces free access to classified transmissions. Stealth technology, which serves a single basic purpose (reduce detection), makes all other defensive options irrelevant if it succeeds.

Military space budgets may never be big enough to buy the optimum defense package. Planners and programmers, who must compromise, might bear the following principles in mind: identify a sensible balance between defensive measures and missions; pick options that blend best; protect complete space systems, instead of isolated components.69/

Chapter 4

U.S. AND SOVIET MILITARY SPACE POSTURES

Only two nations, the United States and Soviet Union, possess extensive military space forces. Opposing concepts, plans, programs, and deployments are similar in some respects, but composite postures are quite different *(Figure 20)*. This brief comparison takes geography, military doctrines, design philosophies, technological competence, budgetary support, and other influential factors into account.1/

POSTURAL SIMILARITIES

U.S. and Soviet military space forces presently share several attributes. Basic objectives and mission priorities are virtually indistinguishable. C^3 structures are much alike. Both, for example, maintain primary control facilities on land, but position supplementary installations in space and afloat. Neither nation has formed a separate military service for space or a military space coalition with any country. Neither deploys extensive space combat capabilities. Space infrastructure on both sides is vulnerable to ballistic missile attacks. Satellites are poorly protected.

BASIC OBJECTIVES AND POLICIES

Official publications, disseminated openly, clearly document U.S. space objectives and supporting policies. Selected excerpts that concern national security summarize collective intent.

The Presidential Directive on National Space Policy, approved on January 5, 1988, specifies that "space leadership" is America's main objective. U.S. "preeminence in key areas of space activity critical to achieving our national security . . . and foreign policy goals" is essential. Four principles underpin that aim:

- The United States is committed to the exploration and use of outer space by all nations for peaceful purposes . . . 'Peaceful purposes' allow for activities in pursuit of national security goals.

- The United States will pursue activities in space in support of its inherent right of self-defense and its defense commitments to its allies.

Figure 20

U.S. AND SOVIET MILITARY SPACE POSTURES
(Early 1989)

	United States	Soviet Union
Basic Objectives		
Deter	X	X
Defend	X	X
Deny	X	X
Support Earth	X	X
Declaratory Policies		
Oppose Hegemony	X	X
Pursue Arms Control	X	X
Organization		
Military and Civilian		
Separate	X	
Inseparable		X
High Command		
Space Commands	X	
Traditional Commands		X
Infrastructure		
Industry		
Dedicated base		X
High production		X
C^3 Facilities		
Homeland	X	X
Allied Territory	X	
Afloat	X	X
Space	X	X
Launch Facilities		
Inland		X
Many		X
Fixed Site	X	X
Military Space Missions		
Communications	X	X
Intelligence	X	X
Weather	X	X
Navigation	X	X
Missile Defense	X	X
Space Control	X	X

Abbreviations: ASAT, antisatellite; BMD, ballistic missile defense; C^3, command control, communications; DEW, directed energy weapons; KEW, kinetic energy weapons; LEO, low earth orbit; GEO, geosynchronous orbit.

Figure 20 (continued)

	United States	Soviet Union
Military Space Systems		
Boosters		
Many types		X
Large quantities		X
Spacecraft		
Missions		
Mainly Unipurpose	X	X
Secondary Common	X	
Quantities		
Many		X
Few	X	
Technologies		
Most advanced	X	
Most costly	X	
Weapons		
Deployed		
Orbital ASAT		X
BMD missiles		X
Land-based lasers		X
EW	X	X
Development		
DEW	X	X
KEW	X	X
Military Space Deployments		
Main Locations		
LEO, Molniya orbits		X
LEO, GEO	X	
Duration		
Long	X	
Short		X
Manned Missions		
Many	X	
Few		X
Long		X
Short	X	
Budgetary Support		
Consistently Strong		X
Inconsistent	X	
Composite Posture		
Most dependent on space*	X	
Most vulnerable	X	
Best prepared		
Peacetime support	X	
Deterrence		X
Combat		X

---

* Depends on scenario. Parity typified peacetime support in 1989, although techniques were quite different.

- The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies . . . and rejects any limitations on the fundamental right of sovereign nations to acquire data from space.
- Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.2/

"Space activities," that document continued, "will contribute to national security objectives by 1) deterring, or if necessary, defending against enemy attack; 2) assuring that forces of hostile nations cannot prevent our own use of space; 3) negating, if necessary, hostile space systems; and 4) enhancing operations of United States and Allied forces."3/

The U.S. Department of Defense (DOD) condensed those instructions from the Chief Executive and Commander-in-Chief, then elaborated a bit: "These goals will be achieved by providing secure, assured means for collecting and transmitting information, and by providing the means to counter aggression through space-related and strategic defense operational capabilities."4/

Western intelligence communities and independent observers must deduce Soviet military space objectives, because authorities rarely disclose details, Glasnost notwithstanding. Available evidence nevertheless indicates that U.S. and Soviet goals are almost identical.

Soviet General Secretary Mikhail Gorbachev in May 1987 declared that "we do not intend to relax our efforts and lose our vanguard position in the conquest of space." Semantics separate that statement from U.S. policy, which calls for "preeminence," but not by much. Defense Intelligence Agency (DIA) deductions, derived from analyses of Soviet space propaganda and deployments, parallel parts of the U.S. Presidential Directive: ". . . attain and maintain military superiority in outer space sufficient both to deny the use of outer space to other states and to assure maximum space-based military support for Soviet offensive and defensive combat operations on land, at sea, in air, and in outer space."5/ Similar findings, prepared independently and in greater detail, list five Soviet objectives:6/

- Protect Soviet tactical and strategic strike capabilities.
- Support Soviet tactical and strategic operations.
- Protect Soviet and client state territories.
- Prevent enemy use of space for military, political, or economic gain.
- Maintain freedom of action in space to further the Soviet system.

Both countries publicly favor political cooperation in space. Neither apparently has firm plans to exploit space economically in the near future, although both are aware of potential rewards. Neither apparently plans to visit lunar libration points anytime soon, to ascertain whether L4 and L5 in fact are stable, or determine how much energy spacecraft must expend to linger long at L1, L2, and L3.

Both countries publicly profess strong concerns for space arms control. That does not mean, however, that respective purposes and negotiating positions always overlap. On the contrary, serious disputes are common. The Soviets, for example, seek a comprehensive ban against the development, testing, and deployment of "space-strike arms," which include weapons associated with U.S. strategic defense initiatives (SDI). America's approach, spelled out in the 1988 Presidential Directive, is more selective: "The United States will consider and, as appropriate, formulate policy positions on arms control measures governing activities in space, and will conduct negotiations on such measures only if they are equitable, effectively verifiable, and enhance the security of the United States and its allies."7/ Mutually acceptable accords, predicated on compromise, will likely have long gestation periods, given those starting positions.

MILITARY MISSIONS

The United States and Soviet Union at this moment understandably concentrate on military space missions that support armed forces on Earth. Other aspects as yet attract little attention.

Intelligence collection is the most diversified mission. Reconnaissance, surveillance, target acquisition, tracking, signal interception, meteorological information, missile warning, nuclear detonation detection, and verification (arms control compliance, post-strike assessments) are prominent components. Navigational assistance that helps land, sea, and air forces locate themselves accurately is a second critical mission. Communications is a third, since findings must reach users in timely fashion. Space satellites that implement some or all of those missions are commonly called "force multipliers," because they enhance strategic and tactical capabilities of all kinds around the world, whether peace, international crises, or war prevails.8/

Soviet leaders adamantly oppose U.S. space-based ballistic missile defense programs. Their version of SDI nevertheless predates ours by many years, and continues apace.9/ Neither side as yet assigns high priorities to space related deterrent and denial missions in a broader context.

POSTURAL DIFFERENCES

Many differences [illegible] U.S. from Soviet military space forces (refer to Figure 20). The United States segregates governmental space activities from the commercial sector, and military from civilian, to much greater degrees. Our National Aeronautical and Space Administration (NASA) has no counterpart in the Soviet Union, although Glavkosmos is acquiring some similar characteristics. Military and civilian space programs in that country are virtually inseparable, with the latter being subordinate (the military share is variously estimated to be 60-90 percent, depending on definitions). U.S. military space commands, described in Chapter 3 are foreign to the Soviet establishment, which emphasizes traditional command structures and centralized control. Interservice competition there is more muted.10/

This discourse limits elaboration to two topics that set U.S. and Soviet military space postures far apart. Dissimilar programming principles guide research and development. Dissimilar deployment practices condition capabilities.

PROGRAMMING PRINCIPLES

U.S. and Soviet military space programming philosophies differ fundamentally in four respects. Authorities in the United States tend to favor technological sophistication over simplicity; multipurpose over unipurpose systems; quality over quantity; and quantum leaps over incremental improvements. Soviet authorities tend to reverse those orders. Exceptions occur on both sides and divergences often are overstated, but such distinctions, by and large, are accurate.11/

U.S. military space technology is superior in many respects. Imagination and inventiveness are evident. The Soviets' Energiya launch vehicle, recently unveiled, looks and performs a lot like Saturn V, which put U.S. astronauts into lunar orbit on December 21, 1968. Their Mir space station is little better than America's Skylab, circa 1973. The Soviet space shuttle borrowed indirectly from U.S. blueprints. Satellites and sensors (but not weapons) generally fit that pattern.12/

Soviet technological inferiority is not due entirely to lack of skill. They prefer simple, tried and true space systems that perform specified missions well without frills. State-of-the-art, they feel, not only is unnecessary but, more often than not, involves avoidable risks. Soviet versions of SDI, for example, modify terminal defense technologies that were in vogue two decades ago. U.S. Phase I layered defenses, under development, demand breakthroughs of considerable magnitude. Conservative, compartmentalized programs of the sort just described limit Soviet flexibility, but U.S. complacency would be ill advised, because steady Soviet progress is closing many gaps.13/

Those policies permit Soviet assembly lines to mass produce relatively inexpensive space equipment and stockpile spares. Few components, much less full systems, phase out. Only one obsolescent booster, for example, has ever retired; it flew from 1962 to 1977; 10 different designs remain in service. Backup accordingly is considerable. Initial development amortization costs are nil in many instance, or nearly so. Large procurement packages keep pro rata operations and maintenance costs comparatively low.14/

U.S. military space programs, in sharp contrast, are caught in "can't win" situations. Cutting edge technologies cost so much that procurement is strictly limited. Small buys, in turn, push price tags higher. Mass production would not always be possible, even if budgets allowed, because some hyper-specialized items are very nearly handcrafted. Spares are out of the question. U.S. systems instead depend on redundant components aboard each spacecraft, which increases life spans and guards against catastrophic failures. DOD policies "vigorously pursue new support concepts . . . aimed at substantially reducing costs while improving responsiveness, capability, reliability, availability, maintainability, flexibility and the ability to operate in peace, crisis and war." Monetary savings, however, likely will remain on the margin, unless radically revised programming principles accompany new support concepts.15/

DEPLOYMENT PRACTICES

U.S. and Soviet deployment practices differ as much or more than respective programming principles. Soviet spacecraft, for example, have little longevity, compared with U.S. vehicles. Their photo reconnaissance satellites normally last no more than two months; the mean lifetime of other types is 1-4 years, depending on missions.16/ High quality U.S. spacecraft live longer, but modernization is relatively slow, because policymakers bypass "better" systems while they wait for the "best".

Deployments begin with reliable boosters and launch sites. The Soviets have both. They are expanding their already versatile stable of expendable and reusable launch vehicles, as shown in *Figure 21*. Each is optimized for particular payloads that vary from light (under 1.8 tons for SL-8) to heavy (more than 110 tons for SL-X-17, which launches the Soviet shuttle). Defense Intelligence Agency estimates that total weight-to-low earth orbit capacity could double by 1992. Approximately 20 fixed-site launch pads are operational at Tyuratam, Kapustin Yar, and Plesetsk (Map 11). Expansion may include the first mobile launch facilities.17/

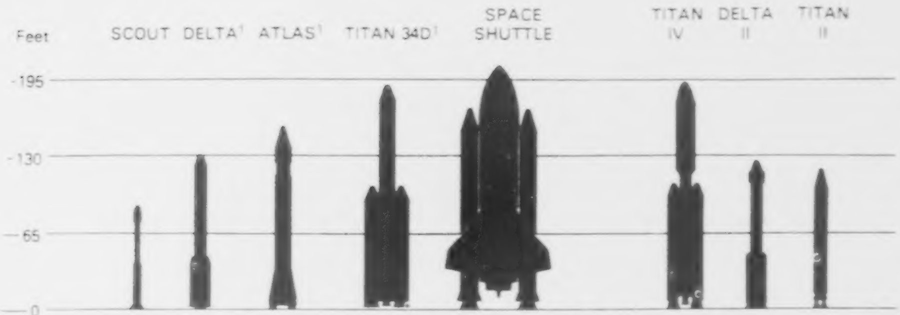
U.S. military space forces lack equivalent launch capabilities. The fleet is small, performance erratic. No astronauts flew between 1975 and 1981, after Saturn boosters retired. Two Titan 34D missions failed back-to-back in August 1985 and April 1986. The shuttle, our largest lift vehicle, was grounded for 32 months after the Challenger disaster in January 1986. Its peak loads approximate 30 tons. Allowable limits for Titan IV, in second place when it finishes flight testing, will be 10 tons less. Other boosters in late stages of development are far below those levels (Delta II, 5.5 tons; Atlas II, 7.5 tons). Space-based SDI components must deploy piecemeal, if at all, until bigger vehicles become available. Debates about their advisability continue. 18/

Soviet launch rates, which average about 100 per year, exceed the U.S. pace 5:1. Payloads routinely are more than twice as heavy as ours. They

Figure 21

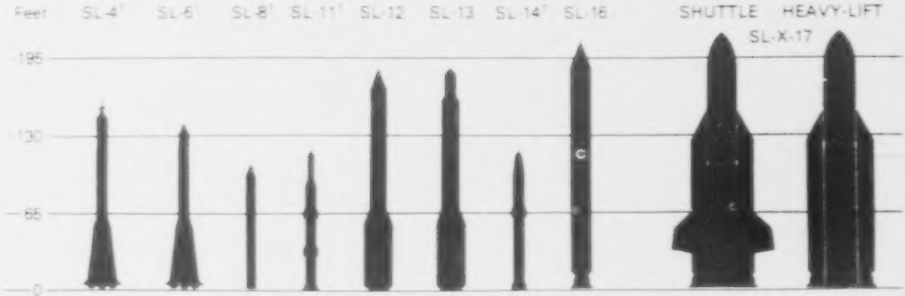
U.S. AND SOVIET SPACE LAUNCH VEHICLES
(As of Early 1989)

US Space Launch Vehicles



Ballistic Missile Derived

Soviet Space Launch Vehicles



Ballistic Missile Derived

Note: Adapted from *Soviet Military Power: 1988* demonstrated impressive surge capabilities during the Falkland conflict in 1982, when 28 space vehicles lifted off during a 69-day period. Potential has since improved. Turnaround times between launches at any given location can be measured in hours or days, according to one former Secretary of Defense, compared with U.S. times that normally take weeks or months.19/

U.S. and Soviet military space forces launch many loads into low earth orbits *(Map 12)*. Equatorial GEO, however, is most suitable for U.S. communication satellites. Four at that altitude (22,300 miles) can constantly cover the globe, except for high latitudes. Geosynchronous orbits also are popular for U.S. missile warning and signal intelligence missions. Equatorial GEO isless attractive to the Soviets for two reasons. Communications from that location cannot reach arctic waters or key bases on the Kola Peninsula and Kamchatka. Soviet spacecraft, bound for GEO all launch from Tyuratam, the southernmost departure site, but nevertheless sacrifice payloads for propellants, because orbital transfers and plane changes burn a lot of fuel. Most Soviet communications and early warning vehicles therefore follow eccentric Molniya orbits (apogee 25,000 miles, perigee 300 miles). Each C^3 satellite overflies the homeland at maximum altitude about eight hours daily. 20/ Neither the United States nor Soviet Union deploy many spacecraft of any kind much beyond GEO.

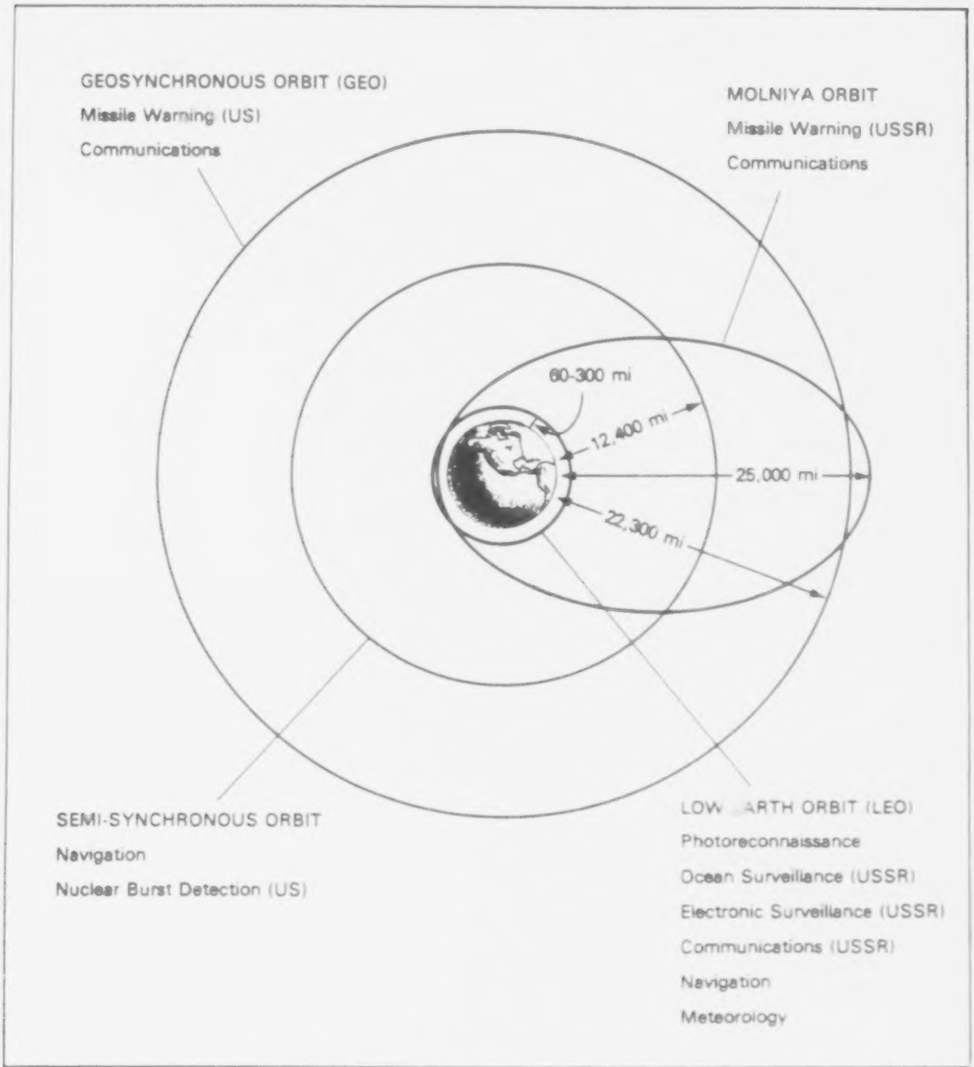
All operational weapons, other than electronic warfare devices, belong to the Soviet Union. The U.S. air-launched, direct ascent antisatellite (ASAT) system may be more sophisticated than the Soviet coorbital vehicle, but deployment is delayed indefinitely, pending congressional approval. Two Soviet land-based lasers at Sary Shagan probably could blind U.S. optical sensors in space. Galosh ballistic missile defense interceptors around Moscow may have modest ASAT capabilities against spacecraft in LEO. Employment as antisatellite weapons, however, would prevent accomplishment of their primary mission, which is to protect the capital city. Even so, Soviet military space forces have some arms at their disposal. U.S. forces do not.21/

The United States set standards for manned space flight with lunar landings between 1969 and 1972. Four Skylab missions followed in 1973; the last Apollo flight in July 1975 terminated all U.S. efforts until the shuttle Columbia lifted off in April 1981. Manned deployments during succeeding years have been few and far between. Department of Defense space policy still directs planners to "explore roles for military man-in-space," and prescribes "a mix of both manned and unmanned systems," but no approved mission for permanent presence has emerged.22/

Manned space flights conversely have been a Soviet specialty since 1961. Permanent manned presence began in 1987 aboard Mir, a modular space station. Soviet cosmonauts, who hold every endurance record except extra vehicular activity ("sky walking"), have accrued three times as much experience in space as U.S. astronauts. Their current best slightly exceeds one year; ours is 84 days, set by a Skylab crew in 1973. Docking and extravehicular activity are parts of the Soviet agenda.23/

MAP 12
U.S. AND SOVIET EARTH SUPPORT SATELLITES

Drawn to Scale



NOTE: Adapted from "Satellites and Anti-Satellites," by Ashton B. Carter, *International Security*, Spring 1986.

COMPOSITE ASSESSMENTS

Composite U.S. and Soviet military space postures, when compared, indicate which establishment is best able to achieve its objectives, despite opposition by the other. Four basic balances must be assessed: peacetime, wartime, present, and projected.

Space forces on both sides are reasonably able to meet routine and crisis requirements. Competence in each case is improving. This assessment therefore concentrates on current and future combat capabilities.

PRESENT BALANCE

Neither U.S. nor Soviet space forces are well postured for war now or in the near future. Ballistic missiles that transit circumterterrestrial space are the main offensive instruments. Both sides are vulnerable, because they possess early warning devices, but little or no defense. Neither deploys many offensive forces for Earth-to-space, space-to-space, or space-to-Earth operations.

Soviet space forces nevertheless are better postured for deterrent and warfighting purposes. Launch/recovery sites, C^3 centers, and logistic support facilities, far distant from hostile frontiers, are less exposed to land, sea, and air attacks that could seriously curtail, even terminate, activities in space (Map 10). Soviet forces on Earth still rely less than the United States on support from space, despite constantly increasing dependency. Few land and air forces deploy far beyond Soviet and Warsaw Pact borders; wire lines reduce their needs for satellite communications. Few naval forces stray far from home waters; satellite C^3 links would be essential to coordinate widely separated and simultaneous surprise attacks, but less useful in other circumstances.24/

The small Soviet ASAT inventory, which some observers consider "primitive," puts defenseless U.S. satellites in potential peril, without running reciprocal risks. That advantage, coupled with diversified boosters that are highly reliable (90-95%), redundancy, and reconstitution capabilities, would serve Soviet space forces well in wartime, compared with U.S. counterparts, which could not surge, play tit-for-tat, maintain high tempo operations, or replace combat casualties expeditiously. The loss of a few Soviet satellites would not dramatically degrade performance; the loss of a few U.S. satellites could seriously curtail U.S. Space Command capabilities.25/

Dependence on support from space, already great, is growing in the U.S. defense community. Orbital sensors increasingly supplement or supplant land-based strategic warning, surveillance, weather and navigation systems. A handful of satellites carry something like 70% of all U.S. long-haul military communications. Commercial voice, audiovisual, radio, telephone, and data transmission also rely on satellite links.26/

Lack of appreciation for trends in space and their implications on Earth hampers planning in U.S. armed services. Recently unveiled Marine Corps amphibious assault doctrine, for example, relies on over-the-horizon assembly to ensure tactical surprise, although military sensors and civilian spies in the sky, who sell photographs to the highest bidder, may already have eliminated "over-the-horizon" locations.27/

Lack of appreciation for fundamentals hampers U.S. offensive, defensive, and deterrent programs. Superboosters, the ultimate key to better capabilities, are on DOD's agenda, but progress is sluggish, because justification is unconvincing. America's experience with intercontinental ballistic missiles (ICBMs) might be instructive in that respect. U.S. designers developed small, accurate missiles. The Soviets originally stressed raw power; precision came later. Their monster ICBMs currently carry many more warheads that have much larger yields and are more lethal than ours. Big Soviet boosters today similarly pave the way for expansion in space tomorrow.28/

PROJECTED BALANCE

The present balance between U.S. and Soviet military space forces is less important than projected postures. U.S. "preeminence," prescribed by Presidential Directive, is possible, provided the Executive Branch, Congress, and American people assign that aim a high priority and are willing to pay a high price. Second place is probable, if they are not, given Gorbachev's intent to preserve a "vanguard position," unless Soviet restructuring compels retrenchment.29/

The prognosis is inauspicious. Gaps between U.S. ends and means are growing, despite technological superiority. Plodding pays off for the Soviets, who play tortoise to our hare. Fits and starts are U.S. specialties; theirs is persistence. We develop, they open options and deploy manned, as well as unmanned, systems. They are, in short, laying a much sounder foundation for military space power, in orbit, at lunar bases, or both.

RESPONSIVE PLANS AND PROGRAMS

Perceived threats to national security interests and objectives condition U.S. space strategies, tactics, and doctrines designed to cope. They also help determine how many implementing forces of what kinds and qualities the United States should deploy in particular time frames and priorities. Responsive U.S. plans and programs therefore depend on sound intelligence estimates. Best case, worst case, and intermediate appraisals are advisable, because enemy intentions and capabilities in space are most difficult to discern.

Optimistic estimates forecast political cooperation and truly peaceful competition in space (as opposed to Lenin's principle of peaceful coexistence, which continues a zero sum struggle by non-military means). Subscribers believe that all countries, formally or informally, will continue to honor the Outer Space Treaty of 1967, which forbids mass destruction weapons in space and military activities on the moon and other celestial bodies.30/ Arms control accords assertedly will reduce, freeze, or otherwise restrict space force quantities, characteristics, installations, and operations, including those of surface-to-surface missiles that transit space. Needs for SDI consequently will cease to exist.

Pessimistic estimates currently predict the opposite. Moscow's main interest in space is military power, according to endorsers. Interplanetary supremacy reportedly will replace world domination as the main Soviet aim; control of the Earth-Moon System will not be enough. Soviet deployments soon will feature offensive space forces that are diversified and profuse, because arms control efforts are bound to fail. No-holds-barred, winner-take-all policies inevitably prevail.

The real world almost certainly lies between those improbable poles. The key question is, Where? "Prepare for the Unexpected" seems a proper motto for U.S. planners and programmers until better answers become available.

Seven nonprovocative actions meanwhile might strengthen deterrence and improve U.S. combat capabilities, if deterrence fails. The first six are nearly cost-free; the seventh is cost-effective:

- Develop comprehensive military space doctrines applicable to the total Earth-Moon System.31/

- Integrate military space more effectively into U.S. national security strategies.

- Emphasize selective and verifiable arms control to confine threats.

- Reduce Army, Navy, Air Force, and Marine Corps dependency on space support, by cross-training that preserves traditional skills, such as communications and navigation.

- Embellish basic research to multiply serendipitous results that might benefit military space programs.

- Employ technological expertise to produce first class systems at acceptable costs.

- Improve passive defenses for selected military space installations and vehicles, with particular attention to innovative hardening and deception.

Seven "big ticket (some say "budget busting") program options comprise a second list. Senior U.S. officials should confirm requirements before they decide to cease research and development; continue R&D at current, reduced, or accelerated rates; and/or deploy particular quantities by any given date:

-- Survivable launch, recovery, and C^3 infrastructure.

-- Heavy lift boosters.

-- National Aerospace Planes (NASP) able to breach the atmospheric barrier in both directions and maneuver in space.[32]

-- Reasonable redundancy and reconstitution capabilities for essential military space systems.

-- Anti-satellite systems.

-- Active onboard defenses for military support satellites on a case-by-case basis.

-- Land-and space-based SDI systems.

Former Secretary of State Henry A. Kissinger, at a March 1974 press conference in Moscow, asked "What in God's name is strategic superiority?"[33] It may be unilateral control of space, which overarches Planet Earth, all occupants, and its entire contents. If so, possessors of that vantage position could overpower every opponent.[34] They might, in fact, impose their will without fighting, a feat that Sun Tzu called "the acme of skill" 25 centuries ago. U.S. military space forces therefore need means to forestall strategic surprise from that quarter and respond successfully, unless best case estimates prove correct as events unfold.

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MEMORANDUM FOR THE COMMISSION ON INTEGRATED LONG-TERM STRATEGY

The Working Group on Technology is pleased to present to the Commission on Integrated Long-Term Strategy a paper, "Recommended Changes in U.S. Military Space Policies and Programs."

This paper is consonant with the Commission's report, Discriminate Deterrence, which made substantial use of the paper's findings and conclusions. The paper provides more comprehensive and detailed information underlying the Commission's report. However, this paper is the responsibility of its authors, and the Commission does not necessarily subscribe to all its details.

The authors of this paper are Albert Wohlstetter and Brian Chow. An earlier draft was the subject of a two-day symposium of selected Working Group members and other experts in the design, manufacture and operation of space systems, and in space policies and programs. The present version was written in October of last year and is published without changes. Subsequent study has only confirmed the analysis and the continuing relevance of the recommendations.

Charles M. Herzfeld

Charles M. Herzfeld
Working Group Chairman

Reproduced from Recommended changes in U.S. military space policies and programs; a paper by the Working Group on Technology, submitted to the Commission on Integrated Long-Term Strategy. Washington, U.S. Department of Defense, 1988. 10 p.

The Pentagon Washington, D.C. 20301-2000

Policies

I. Strategy and the policy objectives of U.S. military space programs.

The U.S. needs military satellite systems that will continue to function or be replaced with appropriate timing not only during peace but to support military operations throughout plausible important wartime contingencies. The U.S. also needs ways of degrading satellites used to support attacks on our allies or ourselves. In a war with the Soviet Union, space will be no sanctuary but will be an important determinant of the outcome of the war.

Space systems can acquire and distribute information critical for the West in defeating a Soviet invasion -- about the gathering and onset of attacks, about the location, status and movements of our own and allied forces and of adversary forces and civil society, and about the weather affecting military operations, and much else. In principle, surveillance satellites can provide information about the location and movement of enemy forces over-the-horizon and at great distances, information useful for battle management or to target specific forces as well as for warning about preparations for war. Communications satellites can distribute information over oceans and large land masses that would be essential for keeping our offense and defense forces effectively directed at achieving essential political military goals.

A Soviet invasion can benefit by analogous information. And the Soviets, much more than the U.S., have plainly designed their space systems to function in wartime. Soviet satellite systems generally are more proliferated. Their communications satellites, for example, are large in number and are placed in several different and widely separated orbits. (Practically all of our communications satellites are at geosynchronous altitude.) Some Soviet communications satellites are small, cheap and easy to replace. The Soviets have large numbers and many types of space launch vehicles. They also have many types of ICBMs, some mobile as well as fixed. And in the past they have converted ICBMs for use in launching satellites and anti-satellites. They have demonstrated their ability to launch many satellites quickly.

How effectively each side is able to use its space systems in broad management of large battles as well as in acquiring specific targets for offense and defense systems can be a key element in deciding the outcome of conflicts between them. Each side will have strong reasons, therefore, both to degrade the other side's use of space and to protect its own. In fact, degrading the space or ground segments of an adversary's satellite and anti-satellite systems used to locate and attack elements of our own satellite systems would be one important way to protect our satellite systems themselves as well as our other military forces.

Do we have to choose between using satellites and having the capability to degrade an adversary's space systems? This is sometimes presented as if it were "a fundamental dilemma" for U.S. policy makers, requiring us to avoid either the use of satellites or any capability to degrade the functioning of another side's satellites if we are to avoid a "spiraling arms race in space". However,

(1) It presents no more a dilemma for us than does, say, our use of both tanks and anti-tank weapons; or for the Soviets in their use of both. It is in fact the normal situation of potential antagonists.

(2) There is no absolute way of separating "offense" from "defense" in space any more than on the surface of the earth or in the oceans or in the atmosphere. Whether a system is offensive or defensive depends on the context and the purpose of its user. A variety of systems used for other purposes can also be used to attack satellites. In fact satellites themselves can be so used, as the Soviets have themselves remarked; and there is no genuine way of eliminating "anti-satellites" without eliminating satellites themselves, not to mention many other systems such as ICBMs which could be used against satellites as well as for other purposes.

(3) The Soviets can attack not only our satellites at low earth orbit with their co-orbital interceptor (which we tend to focus on too exclusively), but, if they use satellites as "space mines", they can also attack our satellites at geosynchronous and other altitudes.

(4) No enforceable ban can prevent the Soviets from developing and deploying in time of peace any of several non-nuclear as well as nuclear means of degrading or destroying key space and ground elements of our satellite systems. And if we do not, in time of peace, prepare either an active or passive defense, or a means of degrading Soviet satellite systems, we cannot, in time of non-nuclear or nuclear war, deter or respond effectively to a confined attack on our satellites with a similar attack on their space systems.

(5) The idea, sometimes suggested, that if the Soviets were to attack elements of our satellite systems we should launch our ICBM force at Soviet cities -- and so to invite the total destruction of our own cities -- is hardly appropriate. Even if there were some extreme circumstance in which that were not irrational, it would be plainly reckless in response to selective Soviet actions degrading our space systems in the course, say, of a non-nuclear war.

(6) Several potential antagonists (and not only the Soviets) can attack vulnerable nodes in the ground segments of our satellite systems.

(7) In fact, there has not been nor is there likely to be, in space any more than on earth, a "spiraling exponential arms race" with each side over-reacting to moves by the other side. Quite the contrary, the United States under-reacted to the growth of the Soviet ability to attack our satellites. It has not used passive or active means to develop robust systems of satellites that could survive such attacks, nor deployed an anti-satellite capability of its own, even though, in space as on earth, there is no basis for the claim that this would lead to an exponential race.

II. Our military satellites have been designed primarily to perform exacting tasks in support of operations in a friendly environment in time of peace and in the transition to an unrestrained massive nuclear conflict. As a result, both the space and ground segments of many of our satellite systems, including the launch and ground control elements, have only a few very expensive critical nodes.

In peacetime, satellites can perform the important functions of monitoring arms agreements, collecting data on military capabilities and providing warning. Our peacetime systems enable a large volume of high data rate communications worldwide for our diplomatic corps and our military forces; provide continuous three-dimensional positioning for navigation worldwide; and serve other useful ends in the peacetime management of our military force.

The use of satellites to support peacetime uses of military forces is important only if it is credible that we could responsibly use our military forces in response to attack and so deter or defeat such attacks. Satellite systems can perform critical functions in such wartime uses of our military force -- provided they can survive.

III. The requirements to support military operations throughout plausible non-nuclear and selective nuclear conflicts are very different from peacetime requirements.

A theater commander in a conventional war, for example, could benefit from a robust source of information that would tell him about the movements of heavy tank divisions or whether an airbase has or does not have aircraft on it. This might be accomplished by satellite systems which trade some peacetime performance for the ability to survive or be restored under plausible repeated attacks.

A concept of operating satellite systems focused on peacetime quite naturally emphasizes increasing the mean time between random failures of our satellites to reduce the cost of replacing them. Our satellites have been so designed and many have been so placed in orbits as to last seven years or more. Our satellites are expensive, but they do not have to be replaced frequently in time of peace.

However, a concept for operating in a war with the Soviet Union would note that such a war is unlikely to last seven years and that it would be the Soviets, not random acts of nature, who would interrupt the functioning of our satellites, and call for us to replace them in a much more compressed time scale than in peacetime. Spare satellites, stored on the ground to replace those disabled, need not have all the power and other components required to function for many years, and may also be placed in much lower orbits, where they would not last as long but which in some cases would improve their performance while they lasted -- more frequent revisit times, less powerful launch vehicles needed, etc. Similarly, the criterion for designing the ground elements of the system and their contribution to total systems cost, recurring and non-recurring, will differ greatly for systems that have to survive for weeks in a very hostile environment than for systems that are designed to function for many years in a benign peacetime environment.

The marginal systems cost to protect or restore the functioning of a satellite system in a given wartime contingency needs to be compared with the marginal systems cost to disrupt or destroy it under the constraints appropriate to that contingency. One or a few satellites costing between a quarter of a billion and a billion dollars each and perhaps weighing as much as 25,000 pounds are hard to protect against, say, non-nuclear space mines weighing a thousand pounds, carrying short-range attack missiles for kinetic kill, and costing only millions or tens of millions of dollars. It is, for example, much cheaper to add maneuvers to the one-thousand-pound space mine than to a satellite an order of magnitude or more heavier; and if so lucrative and scarce a target were protected by a short-range active defense, it is worth it to the attacker to multiply attack missiles to get at least one to leak through. Distributed, less expensive satellites are easier to protect by passive or active measures. The relevant considerations of marginal systems cost for performance in wartime contingencies point toward satellite systems with lighter, cheaper, more easily multiplied, protected and replaceable space elements, and to analogous ground elements.

The origins of our military space program make it easy to understand why we have paid primary attention to peacetime rather than wartime performance of our satellites and help explain some of the mistaken opposition to rethinking our strategy in space now. Just as the laws of the sea had to be created by practice, so limits to the vertical extension of sovereignty above the atmosphere were quite uncertain until the 1960s. When the Soviets orbited satellites over the United States and were preparing to orbit more, there were apparently some who proposed shooting them down. This was clearly a bad idea since we would have lost even more than the Soviets by it. Theirs was a closed society on which we lacked some of the most elementary information about the location, size and technical characteristics of their military forces. They could likely derive such information about us from public sources. The first opposition to our own anti-satellite activity occurred in the context of the peacetime operation of satellites when mutual forbearance was a reasonable prospect. The presumption of a benign environment influenced the design of our satellites themselves and not merely our eschewal of capabilities to degrade Soviet satellite systems.

While this evolution of our space systems is understandable, it is quite mistaken to suppose that we should continue to deploy satellite systems on the assumption that we and the Soviets would continue such mutual forbearance if we were at war.

Programs

I. Monitoring for Warning of Attack on Our Satellites. A prerequisite for effective defense of satellite systems is a timely recognition of attacks on our satellites. This requires a surveillance and tracking system that itself survives and can detect, identify and track threatening space objects in real or near-real time. Currently, we lack such a capability. Moreover, while this sort of system is also very useful for strategic defense, the initial deployment for satellite defense should not be delayed by the added performance requirements and costs of strategic defense. Nor should the system's wartime robustness be significantly sacrificed by a compromised selection of constellation altitudes in order to serve both satellite and strategic defense missions.

II. Lower-Cost, Smaller Satellites for More Distributed and Restorable Systems. Some important wartime missions such as certain essential communications might be performed by satellites that cost so little that they can be replaced more cheaply than the Soviet cost of attack. The goal of DARPA's Advanced Satellite Technology Program (ASTP), or LIGHTSAT, is to support technology development to allow the Department of Defense, in the early 1990s, to field such light and low-cost satellite systems which "will provide support to operational military commanders for force planning and force execution."* The U.S. should support efforts to develop low-cost satellites and mobile launchers. It should be emphasized that these low-cost satellite systems must serve useful wartime missions. For example, we would not be greatly interested in a low-cost system for communications in the post-nuclear attack period if a small number of nuclear detonations could directly destroy most of the satellites in the system or so disturb the environment that the system could not communicate for very long periods of time.

III. Satellite System Designs for Wartime Robustness. For those wartime satellite systems which cannot be made so cheaply, it is particularly important to study many of the system aspects coherently in order to achieve a robust wartime capability. This requires a simultaneous examination of contingencies, satellite wartime as well as peacetime missions, satellite designs, satellite manufacture, satellite launch methods and other ground elements of space systems, satellite defenses, and incentives and means for ASAT attacks of both sides. Most important, we should emphasize, in applying innovations and technological advances, improved wartime performance rather than only or mainly improved performance for peacetime functions.

IV. Active Defense of Satellites. Active defense of satellites has not received enough attention as a complement to passive defenses (e.g., hardening, maneuvering and decoys). Both active and passive defenses are likely to be necessary and will enhance each other synergistically. (Acquiring an active defense of satellites is compatible with and can help in the deployment of a satellite-based ballistic missile defense of the United States or Western Europe but does not entail such a defense.) Passive defenses alone would be inadequate. For example, the lack of active defenses would permit ASAT terminal sensors to discriminate decoys at close range and great leisure. It would be very hard to design inexpensive and credible decoys to fool ASAT sensors with such discrimination.

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*Proceedings of the AIAA/DARPA Meeting on Lightweight Satellite Systems held at the Naval Postgraduate School, Monterey, California on August 4-6, 1987, published by the American Institute of Aeronautics and Astronautics. Page ix.

We should not avoid deploying such an anti-ASAT capability on the ground that it might induce the Soviets to do likewise. The Soviets will deploy such space-based ASATs or anti-ASATs if and when they think them advantageous; just as they have not given up ground-based ASATs because we did. Finally, our anti-ASAT developments should include the consideration of non-physical means of rendering ASAT systems inoperable, such as obstructing the ASAT sensors.

V. Planning Actions for Unilateral Defense. Satellites in some space systems will continue to be so expensive and critically few as to encourage attack unless they are defended. Such systems cannot survive an attack by space mines or other space-based ASAT weapons unless we enforce a self-defense zone around them -- unilaterally, bilaterally or multilaterally -- on the same grounds we use in justifying the self-defense of ships at sea against intrusions that can have no other purpose than a hostile one. We need to make clear that we would take action against a configuration of incursions that can serve no relevant purpose other than to threaten the function of our key satellites. But we also need to design our key satellite systems with enough redundancy and to deploy them in such orbits that the configurations of close-encounters caused by normal satellite operations would not be threatening to our space systems and would be clearly distinguishable from those configurations of close-encounters that are threatening.

VI. Reconstitution Capability and Mobile Launchers. We should expect not only space assets to be attacked but some losses to be inevitable even in conventional or selective nuclear, regional conflicts. It is not a viable strategy to try to protect space assets so well as to avoid losses completely. The U.S. needs a launch capability to replace attrited, as well as spent, satellites. For wartime use, we need ground mobile or submarine launch vehicles or other methods of creating uncertainty enough to survive direct attack.

At least two distinct classes of launch vehicles are likely to evolve. Heavy-lift vehicles designed to launch satellites in peacetime will generally be less expensive on the basis of cost per pound of payload. They will be appropriate not only during peacetime but during some confined conflicts in which launch vehicles do not come under serious attack or remain operable. The second class consists of light-lift vehicles which can be made mobile or movable in submarines or on land. They can be relied upon if heavy-lift vehicles are destroyed. They can also be used during peacetime military exercises, to fill gaps or for surge operations in crises. The R&D community will also find light-lift vehicles useful for launching small scientific and testing payloads.

VII. Satellite Control Systems. In addition to control facilities dedicated to support some individual satellite systems, we rely very heavily on the Consolidated Space Test Center at Sunnyvale, California, and Remote Tracking Stations scattered worldwide. The soon-to-be fully operating Consolidated Space Operation Center in Colorado will be the primary military satellite control facility. However, these facilities and many of the dedicated control facilities are fixed and highly vulnerable to a wide variety of threats including sabotage and missile attacks. These elements, designed essentially for use in peacetime, need to be supplemented by a satellite control system which can operate effectively in a jamming and nuclear environment and under repeated physical attacks. A CONUS-based, mobile, proliferated system is one possibility that deserves serious evaluation.

VIII. A U.S. Capability to Degrade Hostile Satellites at All-Altitudes in Wartime and to Attack Ground Segments of Enemy Space Systems. The U.S. should develop an all-altitude ASAT operational capability. It should have the flexibility to degrade or to deny an adversary's satellite missions temporarily or permanently. Our pursuit of ASAT should not be viewed as a direct response to the Soviet low-altitude, co-orbital ASAT program.

Rather, it is a response to much broader Soviet space activities and capabilities. These inevitably will provide the Soviets with a capability to attack our satellites. What is more, Soviet satellites will contribute greatly to Soviet military operations, including direct attack on our ground, air and naval forces in the course of a war it may wage against the Western Alliance. The U.S. needs the ability to disrupt or destroy the space or ground elements of Soviet satellite systems because they are "force multipliers." We have to be able to defend our satellite systems and to degrade enemy satellite systems for the same reasons that the United States in general needs both a defensive capability and an offensive capability on land, at sea and in the air.

IX. Military Use of Civilian Satellite Systems.

The U.S. should continue to identify and implement cost-effective measures and enhancements to civilian satellite systems, both the space and ground segments, so that they can supplement the military systems during crises and wars. Commercial communications satellites, Landsat, GOES (Geostationary Operational Environmental Satellite) and NOAA (National Oceanographic and Atmospheric Administration) satellites, and their ground nets and elements, would have military uses in communications, remote sensing, and meteorology in certain contingencies.

X. Education and Training in Space System Operations.

In order to utilize space fully for national security, we need not only the physical systems that are tailored to users' needs, but also people in all the military services to be knowledgeable enough to take advantages of these systems and to operate them. More educational and career opportunities should be provided to meet the rapidly expanding utilization of space. Equally important, future space systems should be designed for simplified operations. They should not require highly-skilled and trained personnel to monitor many of the routine activities. Finally, we need to arrive at a balance between the protection of capabilities and sources through compartmentation and the wide tactical dissemination of products in the area of operations.

STRATEGIC DEFENSE INITIATIVE:

PROGRESS AND PROMISE

Preface

On March 23, 1983, President Reagan addressed the American people and said that it was time to turn the technological might of the nation, not to inventing ever more deadly offensive weapons, but instead to creating new instruments for peace and stability. The nation embarked on this bold new enterprise—the Strategic Defense Initiative (SDI)—to find an alternative long-term means to ensure that nuclear war never occurs.

In January 1984, the SDI was established as a research and technology development program. In April 1984, the SDI Organization was chartered to manage the Department of Defense's efforts. A comprehensive SDI program, taking advantage of expertise in the Armed Forces, industry, universities and in the National Laboratories, was created to explore advanced non-nuclear technologies associated with defense against ballistic missiles.

Thanks to dramatic and significant technical breakthroughs over the past few years, we are making progress towards achieving our goals at a more rapid pace than was originally anticipated. Such progress is the product of some of the best scientific minds in the nation and our Allies working on the problem of how to destroy ballistic missiles after they are launched and before they can reach their targets. Brilliant men and women are dedicated to the goal of developing the technology to defend the United States and its Allies from ballistic missiles.

The SDI is vitally important to arms reduction efforts. Our commitment to—and progress within—SDI has helped bring the Soviet Union back into arms reduction negotiations and provided a clear incentive to the Soviet government to negotiate seriously. Most important, our research has shown that effective defenses against ballistic missiles can provide a powerful, practical incentive to progressively deeper reductions in those most threatening weapons. In addition, negotiated agreements could contribute to a stable transition from our current dependence on nuclear retaliation as the basis of deterrence to greater emphasis on effective defenses.

The SDI program is being conducted in compliance with all existing treaty obligations.

This pamphlet reports to the nation on the reasons behind, and progress toward the goals of the Strategic Defense Initiative.

Reproduced from Strategic Defense Initiative: progress and promise.
Washington, U.S. Department of Defense. p. 1-9, 27-31.

IS THERE A CHALLENGE TO OUR SECURITY?

If Deterrence Fails, Our Nation Is Vulnerable Without Ballistic Missile Defenses

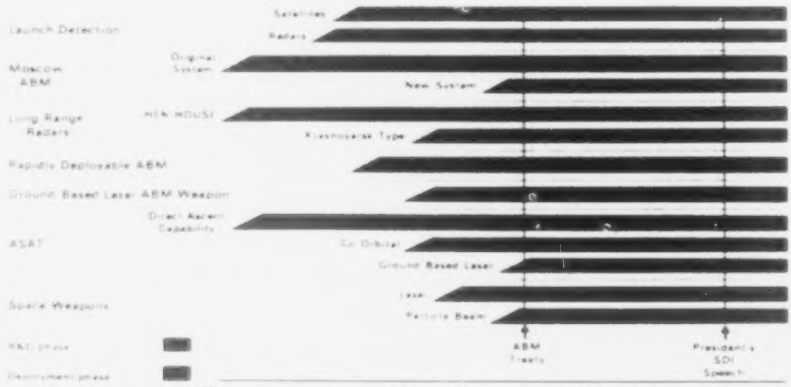
The primary responsibility of a government is to provide for the security of its people. Having the ability and will to prevent acts of aggression against the United States and its Allies is the most certain way to ensure we remain free and independent nations. Preventing aggression, referred to as deterrence, works by convincing a potential enemy that the costs of attacking will be greater than any possible gains. Simply stated, an enemy is deterred from attacking if it knows that it too would suffer enormous damage, or if it knows that its attack would serve no military purpose.

Right now, we can prevent nuclear attack only by threatening retaliation in kind, by convincing an adversary that we could inflict unacceptable damage on him if he attacked. This method of deterrence has been successful for over 40 years. No exchange of nuclear weapons has occurred between the two superpowers. For that matter, there has been no direct military conflict between the United States and the Soviet Union. The success of deterrence based on the threat of retaliation, however, must not make us complacent. We must continue working to make the world safer and more secure in the future.

A safer and more secure world requires action on three fronts: strategic modernization, arms control and strategic defenses. First, as long as the threat of retaliation is our only means of deterrence, we must modernize our strategic offensive forces to maintain a military balance with the Soviet Union. Second, since the world will be safer with lower levels of those forces, we are simultaneously pursuing deep, equitable and verifiable offensive arms reductions with the Soviets. Finally, we are also examining, through the Strategic Defense Initiative, whether we can shift the basis of our security away from the threat of retaliation toward non-nuclear defenses which threaten no one.

The goal of the SDI—being able to defend effectively against ballistic missiles—is often presented as a revolutionary idea, but the basic concept represents a return to tradition. Nations throughout history have deterred attack through a combination of offensive forces to threaten retaliation and defenses to prevent an aggressor force from reaching its targets. That did not change with the nuclear age; through the 1950s and into the 1960s, the United States and the Soviet Union each spent about as much on strategic defenses as on strategic offensive forces. Since the nuclear weapons of that time were carried on bombers, the defensive measures were air defense systems and civil defense.

Soviet Programs For Ballistic Missile Defense And Space Defense Continue To Expand



Soviet programs for ABM and Space Defense (which include advanced technologies and space based weapons) were in place prior to the 1972 ABM Treaty and have continued to expand in scope and size. During the same time period, US ABM/Space Defense research has been limited in scope as well as the level of effort in terms of resources invested.

Potential capability of the Moscow ABM system.

In the 1960s, ballistic missiles became more important in each side's strategic offensive arsenals. The United States explored and found at that time that the technology for defense against ballistic missiles was not ready to be utilized. It was very expensive, used nuclear-armed defensive interceptors, and could be overwhelmed by a large offensive attack. As a result, at that time we adopted the approach that security and stability could best be maintained if each side abandoned defenses, particularly antiballistic missiles. In theory, each side would then be equally vulnerable to attack, and therefore equally able to threaten unacceptable retaliation in case of attack. That idea of mutual vulnerability appeared necessary at that time because of the state of defensive technology, and desirable because it called for balance in offensive forces which would in turn allow for mutual negotiated arms reductions.

U.S. expectations that mutual vulnerability would lead quickly to reductions in strategic offensive forces proved unfounded. Although the Anti-Ballistic Missile Treaty in 1972 severely limited U.S. and Soviet defenses against ballistic missiles, the Strategic Arms Limitation Treaty (SALT) agreements did not reduce weapons, but set ceilings at higher, and unequal, levels. The United States exercised great restraint in offensive forces and effectively abandoned strategic defenses, but the Soviet Union did not. Rather than sharing our idea of mutual vulnerability, the Soviets saw it as an opportunity to create unilateral vulnerability for the West by continuing to add to their strategic ballistic missile arsenal and at the same time developing and deploying strategic defenses.

In summary, we face the challenge of providing a more secure world for our people by maintaining a balance with the Soviet Union of capable deterrent forces and effective arms reduction measures to set those forces at a lower level. To achieve this, we must sustain modernization of strategic offensive forces, pursue verifiable, negotiated offensive arms reductions, and seek the capability to return to the tradition of a stabilizing mix of offensive and defensive forces to meet the threat of strategic weapons.

IS THE STRATEGIC THREAT GROWING?

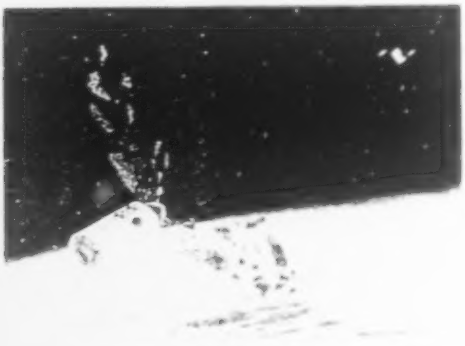
• The Soviet Union Works Constantly To Improve Its Current Defenses And Invests Heavily In Advanced Strategic Defense Technologies

Since 1969, when strategic arms talks began, the Soviet Union has built five new types of intercontinental ballistic missiles (ICBMs) and modernized them nine times. It has also built seven new classes of ballistic missile submarines, five new types of submarine launched ballistic missiles (SLBMs) and modernized them three times. In contrast, we have added limited numbers of one new type of ICBM since 1969. We have deployed only one new class of ballistic missile submarine and two new types of SLBMs. The alarming growth in the number and capabilities of Soviet strategic offensive forces poses a direct threat to our retaliatory forces and lessens our confidence we can deter attacks against us or our Allies.

In addition to improving and increasing the size of its offensive nuclear forces, the Soviet Union continues to seek military advantages through the development and improvement of strategic defenses. The result is an extensive multifaceted strategic defense network as well as an active research and development program in both traditional and advanced strategic defenses. These defenses provide the Soviet Union with a significant defensive capability. In addition, current patterns of Soviet research and development on advanced strategic defenses will provide them with a steadily increasing potential to counter U.S. retaliatory forces in the future.

Today, Soviet defenses are already quite extensive. The Soviet Union possesses the world's only ballistic missile defense system, deployed around Moscow. This system, in place and ready to use, is currently being improved and expanded. The Soviets also have the world's only opera-

The Soviet Union Also Has The Only Operational Weapon System To Attack Satellites In Space



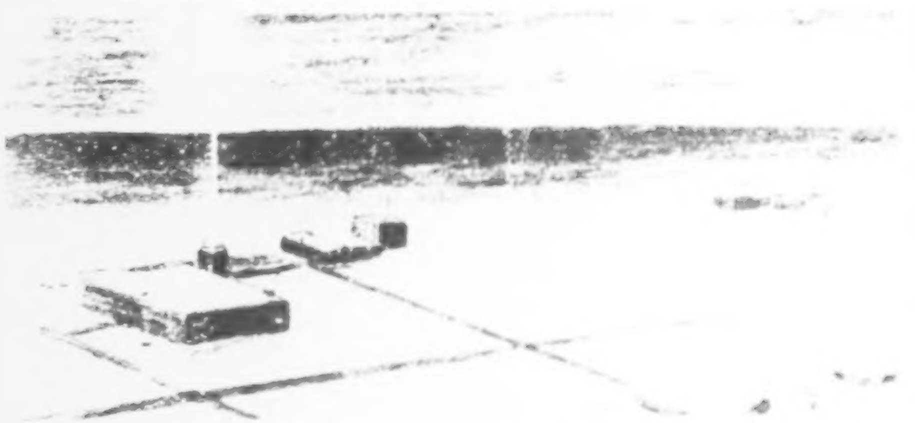
The Soviet's operational antisatellite system is able to attack satellites [illegible] warhead without [illegible] much [illegible]

[illegible] systems. They have extensive air defenses and are constantly improving the quality of their radars, interceptor aircraft and surface-to-air missiles.

Since the 1960s, the Soviet Union has been conducting a substantial research and development program on defenses against ballistic missiles. In 198[illegible] [illegible] Secretary [illegible] noted that Soviet ballistic missile defense research is a broad-based effort and covered the same areas as the SDI program. In fact, Soviet research and development of advanced technologies for defense against ballistic missiles has been substantially far more expensive than our own. The laser program alone employs more than 10,000 scientists and engineers. This activity shows no sign of slowing in the foreseeable future.

The combination of Soviet offensive and defensive developments, if unanswered, may provide the Soviet Union with a decisive military advantage in the near future. The threat of nuclear retaliation may not provide a sufficiently reliable basis for deterrence in the future as it has in the past.

The Soviet Union Is Pursuing Advanced Defensive Technologies



[illegible] directed energy R&D site at Saryshagan proving ground includes ground-based [illegible] antisatellite role today and possibly a ballistic missile defense role in the future.

WHY A DEFENSE AGAINST BALLISTIC MISSILES ?

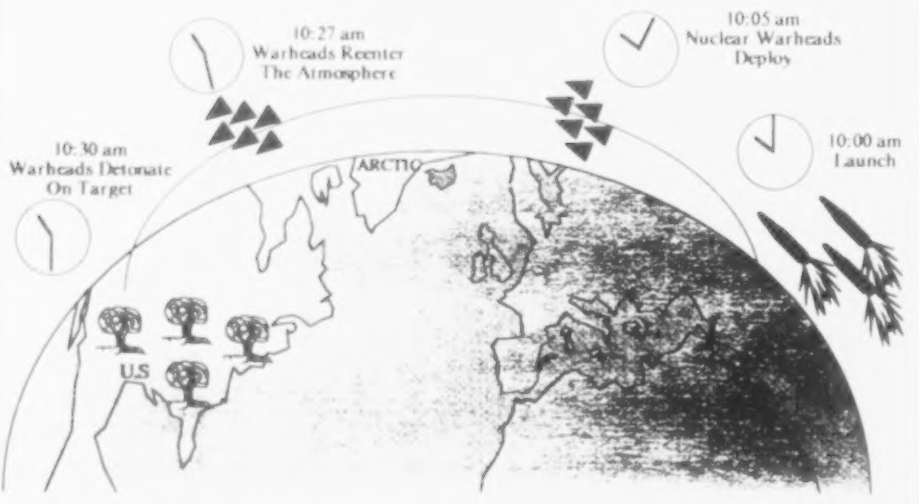
Defenses Against Ballistic Missiles Can Help Deter Nuclear War

This, then, is the context within which we are undertaking the SDI: we are examining the possibility of a more stable, secure deterrence for the longer term, based increasingly on defensive systems. The strategic trends of the last 20 years make that effort essential, while scientific and technological advances make it promising.

The military power of the Soviet Union remains the principal threat to our security and that of our Allies. Soviet improvements to their offensive nuclear forces increasingly threaten our ability to deter aggression. The most threatening weapon in the Soviet arsenal is the ballistic missile. It is deadly accurate, has flight times measured in minutes and is capable of carrying many nuclear warheads.

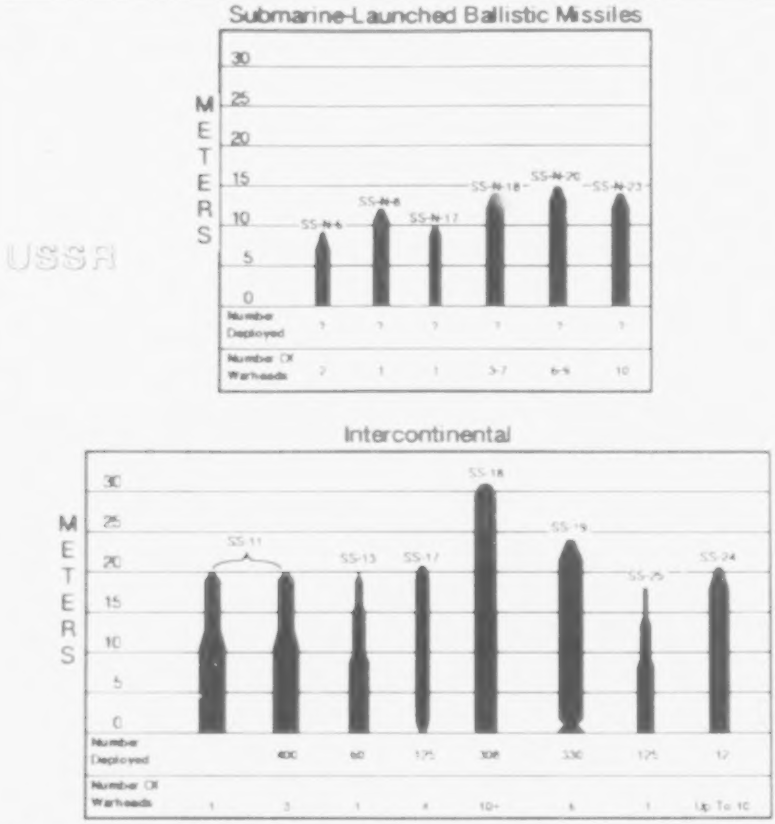
Scientific developments and several emerging technologies now offer the possibility of defenses against ballistic missiles that did not exist earlier. Today, there are multiple approaches based on kinetic energy (e.g., accurate, high velocity interceptors) and directed energy (e.g., high energy lasers) technologies. Also, we are making progress in distinguishing between decoys and actual warheads and managing signal and data processing loads. Supercomputers and multi-spectral sensing may enable us rapidly to find, track and intercept, simultaneously, thousands of targets. We believe rapid advancement of these technologies will permit us to build the defensive weapons and command and control systems for a modern and thoroughly reliable defense against ballistic missiles. These systems will meet the criteria of military effectiveness, survivability and cost-effectiveness at the margin.

A Ballistic Missile Armed With Multiple Nuclear Warheads Is The Most Threatening Weapon In The World



Nuclear-armed ballistic missiles are the most threatening weapon in the Soviet arsenal. In about a half hour, they can deliver nuclear warheads on targets in the United States.

The Soviet Union's Strategic Ballistic Missile Arsenal Continues To Grow



This diagram shows the total number of Soviet land-based intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) and their warheads. These are the weapons that an initial, first generation Strategic Defense System would be designed to defend against.

We do not underestimate the difficulties, however. A defense against ballistic missiles is a challenging technical undertaking. Nonetheless, the research supported by the Strategic Defense Initiative has progressed more rapidly than many thought possible. The possibility of a more secure world, one protected increasingly by defenses instead of offensive nuclear weapons, is closer to becoming a reality.

Emerging defensive technologies, vigorously researched under the Strategic Defense Initiative program, could be used to greatly enhance deterrence. Strategic defenses, by having the capability to destroy ballistic missiles and nuclear warheads before they reach their targets, would reduce the confidence Soviet leaders have in their ability to launch a first strike and destroy the forces we would use to retaliate. Lacking confidence that they could destroy our retaliatory forces, and faced with the threat of enormous damage to their nation if we retaliate, Soviet leaders would not risk an attack.

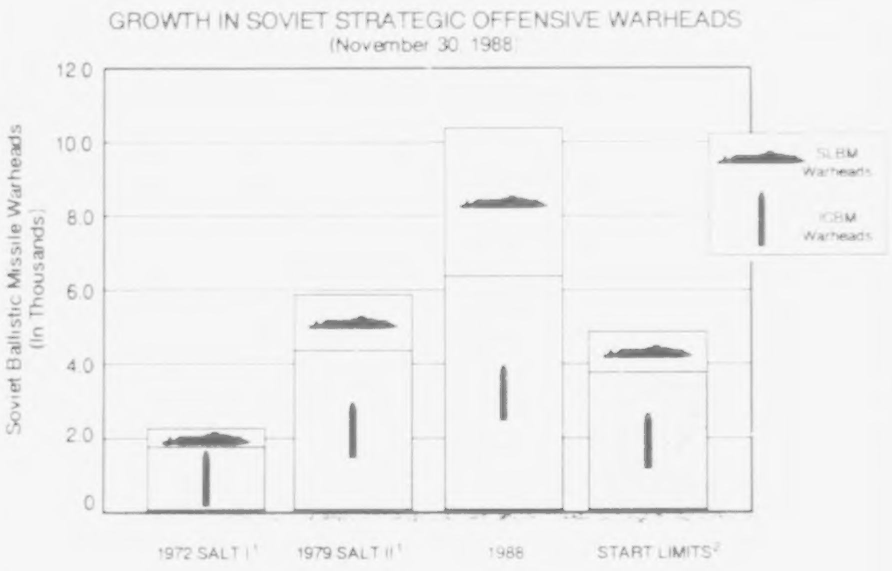
Further, strategic defenses could provide protection against a small attack, whether it is an accidental launch, an unauthorized launch, or an attack by a nation other than the Soviet Union. This is in sharp contrast with the current situation. If an attack were made today, we would not be able to stop a single nuclear warhead from reaching its target.

Defenses against ballistic missiles provide a powerful incentive to negotiate deep reductions in ballistic missiles, increase stability and reduce the risks to our security by providing insurance against possible Soviet cheating on arms control agreements. Increasingly capable defenses deployed over time would reduce the military utility of ballistic missiles further and further. A deployed Strategic Defense System would be even more important in a world of balanced reductions in offensive nuclear weapons. Strategic defenses can help to ensure stability during the transition period as we are reducing our ballistic missiles. Finally, given the Soviet Union's record of treaty violations, reliable, cost-effective and survivable strategic defenses could help ensure that once we have negotiated deep reductions in the number of ballistic missiles, we would not be threatened if the Soviets decided to cheat on that agreement.

The SDI program is part of the U.S. commitment to the defenses of NATO and other Allies. President Reagan, in March 1983, emphasized that the SDI program is designed to enhance Allied as well as U.S. security. The U.S. government has engaged in continuing consultations with our Allies on strategic defenses. Our Allies support, and many participate in, the SDI program. We are examining technologies for defenses against all ballistic missiles, including those which pose a particular threat to our Allies.

In summary, the SDI program has the potential to move us toward a safer world, one with reduced levels of nuclear arms, and with deterrence based increasingly on defenses rather than the threat of retaliation. We will continue our efforts to convince the Soviet Union to join us in working out a stable transition toward this logical and achievable goal.

Despite Arms Control Efforts, Success In Restraining Soviet Military Developments Has Been Limited



[1] NOTE: Neither SALT I nor SALT II placed limits on ballistic missile warheads. Data reflect Soviet ballistic missile warheads on these dates.

[2] The United States and Soviet Union have agreed to a sublimit ceiling of 4900 on the aggregate number of ICBM plus SLBM warheads.

HOW WOULD DEFENSES WORK?

[illegible] Shows Us How To Defend Against Ballistic Missiles And Why Effective Defenses Are Now Feasible

The requirements for a successful defense are generally the same throughout history and certainly apply today. If he has the means, the defender has traditionally chosen to engage the attacker in all phases of the battle with many different types of weapons. This disrupts the structure of the attack and increases the cost and uncertainty of attack planning. We refer to this strategy as "defense-in-depth." We find that the concept of a defense-in-depth applies to a ballistic missile attack as well. Technology today, unlike two decades ago, provides us with the potential to implement such a defense.

We need multiple defensive layers capable of engaging missiles in all phases of flight. This requires defensive weapons capable of intercepting targets in the boost phase (before multiple warheads are dispensed), the post-boost phase (as the missile releases the platform or "bus" carrying all its warheads), the midcourse phase (the longest period of time as the warheads coast above the atmosphere towards their targets) and the terminal phase (as warheads reenter the atmosphere). A capable command and control system also is necessary to manage the defensive battle, as is the ability to detect and track attacking missiles and then warheads in an accurate and timely fashion. We believe strategic defense technologies researched under the SDI will provide the basis for the defensive systems necessary to build a "defense-in-depth" against a ballistic missile attack.

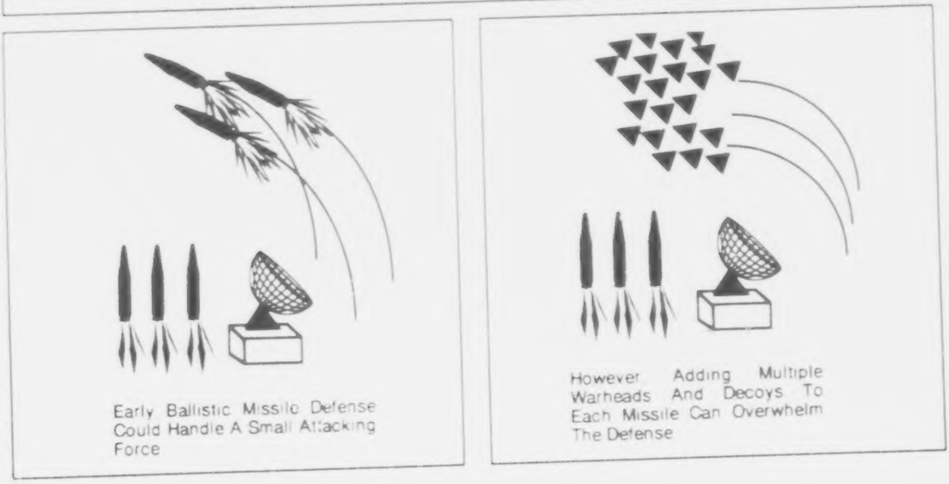
Studies have shown that a multi-layer defense against ballistic missiles could be extremely effective because layers would provide many opportunities to destroy the nuclear warheads before they reach their target:

- Some missiles could be destroyed shortly after launch as their engines burn and boost their warheads into space. Destroying a missile with a single interceptor during the boost phase eliminates all of the nuclear warheads and decoys it carries. This in turn would make the job of later defensive layers easier.

- Next, we could intercept those nuclear warheads that survive the boost phase by attacking them during the post-boost phase. During this phase, we would target the platform on top of the missile that dispenses the nuclear warheads. By destroying this post-boost vehicle, we could destroy all the warheads not yet released.

- The relatively long midcourse phase of flight again offers us time to exploit advanced technologies to locate, identify and destroy the individual nuclear warheads that have been released and will travel for about 20 minutes through space towards their targets.

As Shown In the 1960s, A Terminal Phase Defense Against Ballistic Missiles By Itself Can Be Easily Overwhelmed



Early Ballistic Missile Defense Could Handle A Small Attacking Force

However Adding Multiple Warheads And Decoys To Each Missile Can Overwhelm The Defense

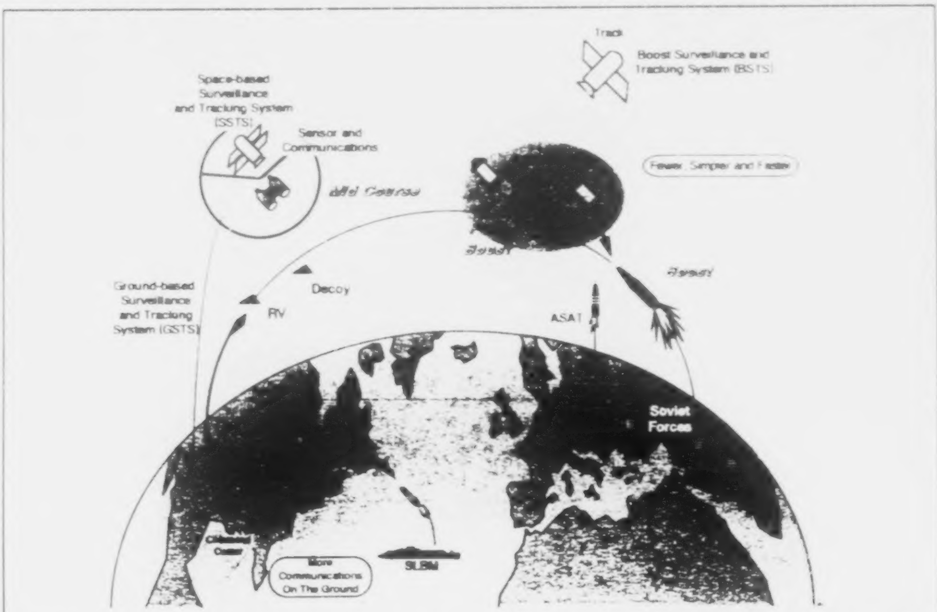
- Finally, those warheads that survive the previous layers of defense could be attacked during the terminal phase—as they approach their targets.

It was recognized early that it would be very difficult to deploy a comprehensive, multilayer strategic defensive system all at once. Therefore, a phased deployment of a Strategic Defense System has been conceived as the most reasonable way to achieve the program's goals. Each phase of the system would enhance stability by significantly contributing to the defense against a Soviet nuclear attack on the U.S. and its Allies. Each defensive layer of the system (boost, post-boost, midcourse and terminal) would have sensors, weapons and battle management in order to engage an attacking ballistic missile in one or more phases of its flight.

Phased deployment considers four key factors: time, technology, defensive missions and responsive threats. The concept recognizes that some of our efforts and technologies will mature faster than others. The approach accepts the fact that the deployment of a defense must take place over time. Each phase of deployment would effectively defend against the threat that is anticipated for its employment period. As other technologies continue to mature and are deployed, they would improve the capability of a Phase One system so as to meet evolving threats. Follow-on phases would utilize these newer technologies and provide additional capability to perform new and highly demanding defensive missions.

The basic purpose of the defense, beginning with the first deployment, would be to both reduce Soviet confidence in the military utility of its strategic ballistic missile force and to defend against an actual Soviet attack. The military objective of Phase One would be to enhance the U.S. deterrence posture by being able to deny the Soviets their objectives in an initial ballistic missile attack. Achieving the Phase One objective would enhance deterrence in two ways. One, it could greatly decrease the Soviet confidence that the objectives of its initial attack would be met. Two, it would increase the likelihood that the U.S. and its Allies would be able to respond to aggression effectively by protecting themselves from attack. Likewise, follow-on phases would build on this important capability.

The Key To Achieving A Defense-In Depth Became Obvious: A Multilayer Defense Against Ballistic Missiles


Track
Boost Surveillance and Tracking System (BSTS)
Space-based Surveillance and Tracking System (SSTS)
Sensor and Communications
Fewer, Simpler and Faster
Ground-based Surveillance and Tracking System (GSTS)
Decoy
RV
ASAT
Soviet Forces
More Communications On The Ground
SLBM

The key to effectively defend against ballistic missile attack is to intercept the missiles and their warheads throughout their flight. Such a system would combine both space- and ground-based components to counter ballistic missiles. Illustrated here is the current Phase One concept of a Strategic Defense System (SDS). It includes space- and ground-based sensors, space- and ground-based interceptors and command and control systems.

DOES STRATEGIC DEFENSE COST TOO MUCH MONEY?

Progress In Developing Effective Defenses Against Ballistic Missiles Is Limited By Funding

We need to place the SDI budget in perspective. Too many people have made and are continuing to make alarming, inaccurate cost claims. SDI funding for the current year is about at $3.7 billion. This figure is approximately one percent of the defense budget and only one-third of one percent of the entire federal government budget. This is not an overwhelming sum of money considering the potential uses of SDI research in defending this nation. In comparison, each year tens of billions are spent on alcohol products, $20 billion on soft drinks and even more on tobacco products and jewelry.

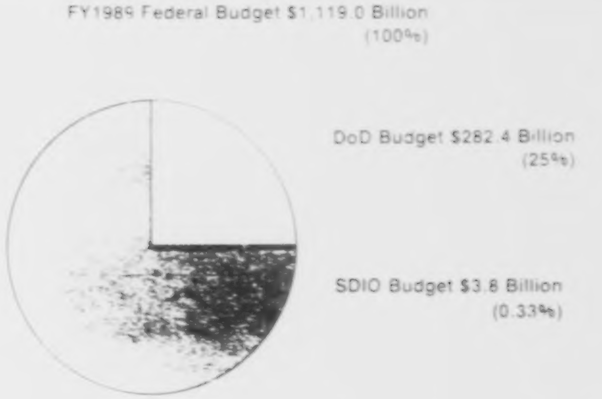
The Department of Defense estimates that the first phase of a Strategic Defense System will cost $69 billion in current year dollars. This figure represents a substantial cost reduction from earlier estimates. This overall reduction was achieved largely through specific cost reductions in the Space-Based Interceptor system. The SBI element alone was reduced from $52 billion to $18 billion. This cost reduction, along with others, reduced the estimated acquisition cost of the first phase of a Strategic Defense System from the earlier $115 billion to $69 billion. SBI cost reductions result in large part from increased interceptor performance and from more capable seeker (sensor) technology and design. This permits a cut in the number of interceptors required for the system while maintaining the effectiveness of the entire Phase One system by transferring functions to other elements of the system.

The estimated cost for the Phase One system includes the costs for demonstration and validation, development and eventual deployment including launch. Since these costs would be spread over at least a decade, the fraction of the defense budget used to achieve this initial system would be only a few percent per year.

We have requested enough money from Congress to research the technologies and provide the information necessary to make an informed decision on strategic defenses. Each year budget cuts have reduced the number of SDI technologies being researched. Some projects are eliminated; some projects are stretched out or delayed. The result of this is a delayed program with more technical risk.

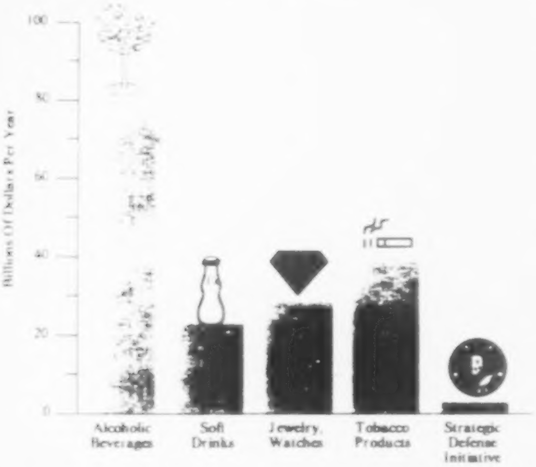
The SDI program emphasizes creating the knowledge necessary to make an intelligent choice regarding strategic defenses. A key issue is whether the SDI program will be supported at a level that will produce a system in time to meet projected threats.

SDI Is A Small But Vital Piece Of The Overall Defense Budget



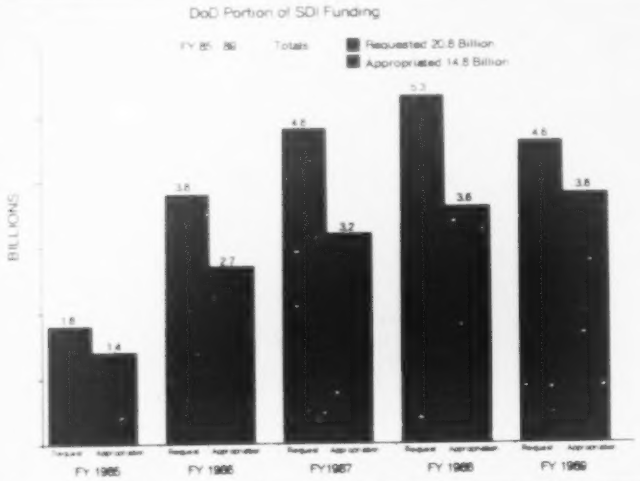
This pie chart illustrates the SDI funding level for Fiscal Year 1989 as a percent of the overall Federal budget. SDI's slice is less than one-third of one percent.

The SDI Budget Must Be Examined In Proper Perspective



This diagram puts the SDI budget in another perspective. It compares the amount of money Americans spend annually on selected items to the annual SDI budget.

[illegible] For SDI Are Based On What We Need For Technology To [illegible]



This bar graph shows the disparity between the funds requested for the SDI program and the amount appropriated by Congress. Such budget cuts reduce the number of technologies that can be researched. Some projects have been eliminated, while others have been delayed.

ARE THERE OTHER USES FOR STRATEGIC DEFENSE TECHNOLOGY?

The Technological Advances Created By Strategic Defense Research Promises to Benefit Medical Science And American Industry.

Just like the APOLLO space program, strategic defense research is developing technologies which have many uses in civilian life as well as other defense projects. SDIO has set up the Office of Technology Applications to help the flow of unclassified information to qualified universities, business and entrepreneurs. In fact, many of the new technologies have already benefited medical science and industry and other defense programs.

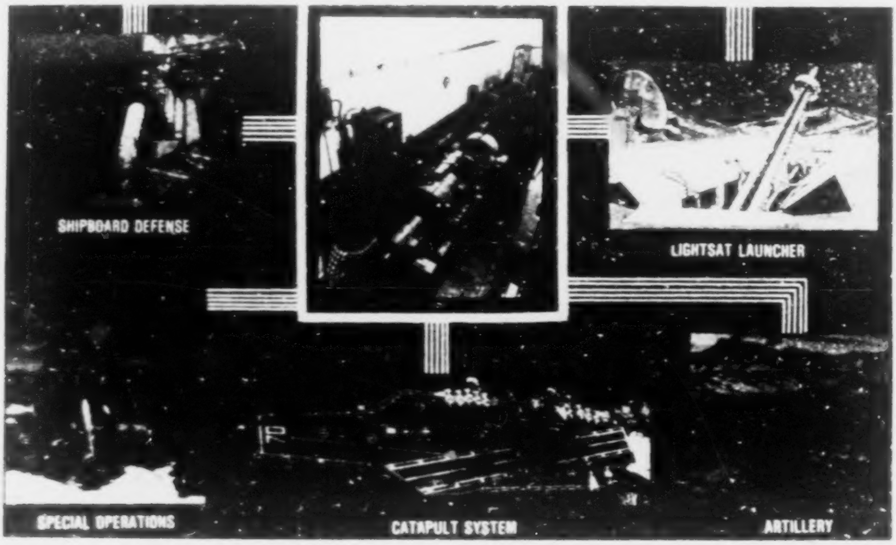
The Medical Free Electron Laser program was initiated to establish facilities for biomedical research. Results have been impressive. Lasers promise to simplify and shorten the time for the delicate surgical procedures used in such operations as hip joint replacements and eye surgery. Lasers, combined with specific chemicals, can actually help kill viruses such as measles and herpes. Lasers and particle beams also show promise to help in the treatment of some cancers.

Other civil applications for SDI technologies are numerous. Some examples include: new materials to repair human bone and soft tissues; ceramic bearings for longer life automobile engines; a method to preserve foods without potentially harmful chemicals; innovative methods to combat acid rain; new freon-free compressors to help preserve the ozone layer; and use of lasers to inspect the safety of our bridges. Other uses for advanced technologies to improve everyday life are limited only by our imagination.

Free Electron Lasers Show Tremendous Promise For Medical Applications

SDI Free Electron Laser technology has a significant potential for applications in medical research. At the direction of Congress, the Medical Free Electron Laser program was initiated within SDIO to establish research facilities and conduct biomedical and materials research.

SDI Research Has Numerous Applications To Other Defense Programs



SDI's Electro-Magnetic Gun technology has potential applications to other military programs. Illustrated here are just a few military uses for this important technology.

SDI technologies are being applied to a wide range of defense programs which promise to improve the [illegible] and survivability of our conventional forces. [illegible]

[illegible]

SDI's [illegible] Electro-Magnetic [illegible]

The SDI-sponsored hypervelocity gun technology [illegible] long-range artillery. These applications [illegible] the range of conventional [illegible] Rapid fire hypervelocity [illegible] can provide [illegible]

[illegible]

SHOULD WE CONTINUE TO EXPLORE STRATEGIC DEFENSES?

. . . SDI May Be Our Best Hope For Eliminating The Threat Posed By Nuclear-Armed Ballistic Missiles

Over the years, the prospect that our offensive nuclear forces could survive a Soviet first strike, and then retaliate effectively, has been a concern. The situation can only get worse in the future if current trends in Soviet offensive and defensive forces continue. We must look for an alternative—to seek a better basis for deterrence. That is the goal of SDI—to determine the feasibility of an effective defense against ballistic missiles which would enhance deterrence, strengthen worldwide stability, and increase the security of the United States and our Allies.

Five years after its inception, the SDI program has made substantial progress: technology is moving rapidly forward and strategic thought has shown that there are ways to transition, in a stable way, from an offensive to defensive deterrence policy. When the program began, there was great question whether such a defense was technically feasible. However, scientists and engineers throughout the nation and in many Allied countries went to work, building on scientific research that had been conducted over the past decade. Their efforts are producing substantial evidence that sophisticated defenses are achievable.

Many formidable barriers and difficulties lie ahead, but these can be overcome by persistently pursuing the SDI program. The substantial progress made in the last few years offers even more hope for a wide range of alternative future defenses against ballistic missiles to support future decisions. It is too early to decide today whether to build defenses against ballistic missiles, simply because much research and technology development still needs to be done.

Currently, we have no defense against a ballistic missile attack. The SDI program is creating the technical knowledge necessary to provide many options for an effective defense. In the future, the leaders of the United States can decide if and at what level and when to build strategic defenses. Today, we are creating and testing various options. These options will give a future President and Congress a reasonable choice whether or not to deploy defensive systems for this nation. The task before us today is to continue working toward the goal of determining if effective defenses are feasible and if they are, to form the basis for their development and deployment.

Advances In Defensive Technologies Are Moving At A Fast Pace

The United States has no defense against ballistic missiles. This simulation at the National Test Facility, Colorado Springs, Colorado, shows the kind of large scale Soviet ballistic missile attack that SDI would help to prevent.

SDI Progress & Promise Update

When President Bush entered office he called for a comprehensive review of our national security strategy and objectives. In doing so, he pressed his advisors to "challenge assumptions" concerning previous national security policies and programs, including the Strategic Defense Initiative. Based on this review the President has determined the following with respect to the SDI program:

1) The goals of SDI remain sound. In pursuing SDI we do not seek superiority, but to place deterrence on a more stable basis by moving toward an increased reliance on defenses;

2) The pursuit of a robust SDI program provides a hedge against any near-term Soviet decision to rapidly expand its anti-ballistic missile capability beyond that allowed by the ABM Treaty;

3) We will continue to vigorously pursue options for layered defenses with both space- and ground-based elements. Layered defenses offer substantial advantages in terms of defense effectiveness and imposing uncertainty on Soviet war-planners;

4) The SDI program will continue to retain the important balance between development of mature technologies for an initial system and research of advanced technologies for follow-on systems;

5) We will emphasize program flexibility and continue to aim for deployment of a system that will meet the established Joint Chiefs of Staff requirements for a Phase One Strategic Defense System (SDS). We are evaluating the potential of the most rapidly advancing technologies such as Brilliant Pebbles; and

6) The SDI program will continue to be conducted in full compliance with all U.S. international obligations, including the ABM Treaty.

The changing nature of the threats we face and the emergence of promising technologies argue strongly in favor of continuing the pursuit of a robust SDI program. In addition, we must not succumb to Soviet pressures to constrain our research endeavors and allow them to maintain an edge in such a capability. The United States continues to have solid strategic and geopolitical reasons for pursuing SDI.

At President Bush's direction, the pace and scope of the SDI program are structured to support an informed deployment decision by the President within the next four years.

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CRS Issue Brief

The Strategic Defense Initiative: Issues for Congress

Updated February 28, 1990

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The Strategic Defense Initiative: Issues for Congress

SUMMARY

Since its inception in 1983 the Strategic Defense Initiative (SDI) program has been characterized as a long-term technology research program to examine the feasibility of developing defenses against ballistic missile attack. Included in the program is research into relatively mature and more exotic weapon concepts and sensor technologies, battle management elements for command and control purposes of an eventual SDI system, and a range of supporting technologies to meet the needs of deploying an effective SDI system. In addition, the SDI program is examining nuclear energy both as a power supply and as a source for weapons.

Although it met with initial skepticism, many U.S. allies and foreign firms are participating in the SDI program, though at levels far lower than originally expected.

The United States is not alone in conducting research in strategic defense technologies. The Soviet Union also conducts research in these areas, although the scope and purpose are unclear and remain controversial. The Soviets have also deployed an anti-ballistic missile system (permitted by treaty) around Moscow.

One of the key policy issues of current interest in the Congress concerns the appropriate level of funding for SDI; on this matter there is widespread disagreement. In addition, there remains considerable controversy over both the near- and long-term arms control implications of the SDI program. On both issues, congressional decisions play an important role in the SDI program.

Also, President Bush has said that he strongly supports SDI research and would deploy a defensive system when it is ready. His Administration has reduced funding for SDI by about $1 billion for FY1990 and about $8 billion for FY1990-FY1994. Even so, the Bush Administration is striving to keep the SDI program focused toward a 1992 decision on whether to deploy an initial SDI system.

This issue brief gives an overview of the SDI program. It describes the development and status of the SDI program, provides information about U.S.-allied participation in SDI, discusses Soviet strategic defense efforts, raises key funding and strategic policy issues of interest to Congress, and tracks SDI through the current budget and legislative process. Further references are provided.

ISSUE DEFINITION

The Strategic Defense Initiative (SDI) is perhaps the most controversial U.S. defense program. It challenges long-standing assumptions about national security, strategic policy, arms control, and the U.S. relationship with its allies and the Soviet Union. The program raises, as well, fundamental questions about the technical feasibility, costs, and potential trade-offs of ballistic missile defenses.

In 1987, the Reagan Administration focused the SDI program toward a specific, initial deployment objective. While the decision whether to deploy the first phase of an SDI system is still a few years away, Congress is being asked to fund SDI this coming year so that such a decision can be made in 1992. Meanwhile, the Defense Department and the SDI Organization continue to refine their preferred Strategic Defense System (SDS) that would be deployed.

BACKGROUND AND ANALYSIS

Background

Reagan Administration and SDI

On Mar. 23, 1983, President Reagan delivered a nationwide address in which he spoke of a long-term national security goal to eliminate "the threat posed by strategic nuclear missiles," and render such weapons "impotent and obsolete." This address became known as the President's "Star Wars" speech and it launched a major, controversial reexamination of U.S. strategic nuclear policy.

Following the address, President Reagan authorized two studies to examine the potential role of strategic defenses against ballistic missile attack. These were known as the Defensive Technology Study (or Fletcher Study) and Future Strategic Strategy Study (or Hoffman Study).

As a result of these studies, which advocated pursuing ballistic missile defenses (BMD), and other Department of Defense (DOD) recommendations, the Administration established the SDI program in January 1984. The military services already had ongoing research programs on various facets of BMD. These efforts were brought together in a more intensive and centralized effort. The SDI Organization (SDIO) was headed by Air Force Lt. Gen. Abrahamson until early 1989. Lt. General Monahan is his successor. As stated, the goals of the SDI program are to provide strategic defense options that would eliminate the threat posed by ballistic missiles, and thereby:

-- support a better basis for deterring aggression;
-- strengthen strategic stability; and
-- increase the U.S. and allied security

Later, the Administration outlined its criteria for evaluating a potential SDI system. In a speech on Feb. 20, 1985, Ambassador Paul Nitze, Special Adviser to the President and the Secretary of State on Arms Control Matters, indicated that such a system must be: (1) survivable; and (2) cost-effective at the margin before it could be deployed. In other words, the United States would not deploy an SDI system unless it could survive an attack against it, and unless the cost of adding more defenses was less than the cost to the Soviets of their adding more offensive systems to overcome U.S. defenses. These criteria were reaffirmed as Administration policy in June 1985.

Congress accepted the survivability and cost-effectiveness criteria, stipulating that any strategic defense system developed as a result of the SDI program may not be deployed in whole or in part unless the President certifies that the system meets these criteria. Congress indicated that a cost-effective SDI system would have to be able to maintain its effectiveness against the offense at less cost than it would take the Soviets to develop offensive countermeasures and to add more offensive systems to overcome the SDI system. This definition of cost-effectiveness was included in the FY1986 Defense Authorization Act (P.L. 99-235, Section 222).

The Administration defined and adopted a specific SDI deployment goal in 1987. This concept, referred to as "phased deployment" simply means the incremental deployment of SDI technologies in distinct phases over an extended period of time. A Strategic Defense System (SDS) envisioned by the Administration would be the culmination of several different SDI deployment phases consisting of ever-evolving SDI technologies.

The first phase, or Phase I, has been approved for entry into the DOD weapons acquisition process, which means that various SDI ground- and space-based missile interceptor technologies and sensors have been advanced as a package to a higher-paced level of testing and development. Whether these candidate technologies succeed in meeting various mission objectives remains to be seen. Nonetheless, the SDI program has been reoriented, emphasizing the Administration's effort to make an SDI deployment decision in the early to mid-1990s. The current emphasis is on developing the space-based interceptor portion of an SDS to accommodate a large number of single interceptors called "Brilliant Pebbles." (See CRS Report 89-563, Brilliant Pebbles: Implications for the Strategic Defense Initiative.)

Allied Response to the SDI Program

U.S. European allies were not consulted prior to the President's speech and initially viewed Reagan's "Star Wars" effort with some alarm. They generally voiced concerns that SDI might contribute to a "decoupling" of U.S. and European security, lead to abandonment of offensive nuclear deterrence, upset U.S.-Soviet relations, and challenge Europe economically as the United States pursued a vigorous advanced technology program with potential applications for the commercial sector. While the allies still oppose any BMD program that threatens the 1972 ABM (Anti-Ballistic Missile) Treaty, currently there seems to be strong support for SDI research conducted within the limits of the Treaty.

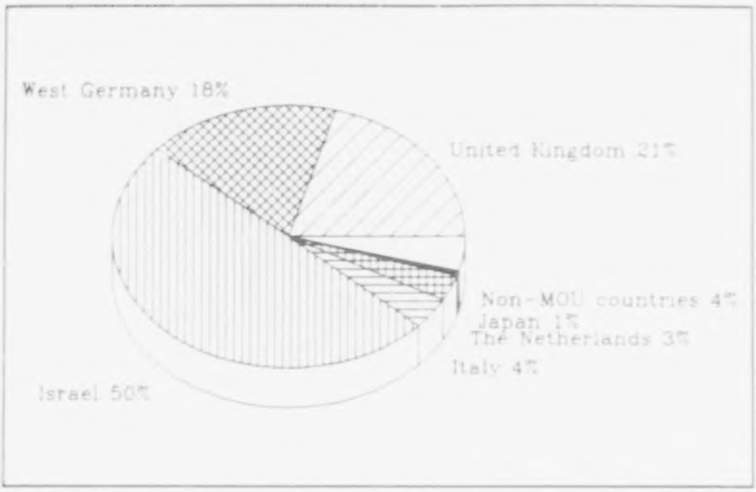
In March 1985, the Reagan Administration solicited allied participation in the SDI program to gain technical expertise and political support for SDI. Several governments said they would not participate in SDI (such as France, Canada, Denmark, Belgium, the Netherlands, and Norway), and some of these remain critical of the program. These same countries indicated, however, that private industry is free to contract directly for SDI work. Such participation includes (to date): France ($13 million); Canada ($2.5 million); Belgium ($94,000); and Denmark ($30,000).

Other governments have undertaken negotiations with the United States and some of them have signed agreements regarding industrial and government participation in SDI. These are listed below.

-- Great Britain signed a Memorandum of Understanding (MOU) with the United States on Dec. 6, 1985, which outlined a framework for British scientists to participate in SDI research. About $77 million in SDI contracts have been awarded.
-- West Germany signed a MOU with the United States on Mar. 27, 1986. About $66 million has been awarded.
-- Israel signed an MOU on May 6, 1986, and has been awarded about $185 million in SDI contracts (includes $32 million contribution by Israel).
-- Italy signed an MOU on Sept. 19, 1986, and has been awarded $14 million in SDI contracts.
-- Japan signed an MOU on July 21, 1987, and has been awarded $2.2 million in contracts.
-- The Netherlands signed a Memorandum of Agreement (MOA) on July 21, 1987, and have received about $12 million in SDI contracts, including a $7 million contribution by the Netherlands.

To date, some 220 contracts have been awarded to foreign companies for a total of $371 million. This does not include any efforts by foreign firms under subcontract to U.S. companies doing SDI work. See figure 1.

Figure 1
SDI-Allied Contract Awards



Program Overview

Department of Defense

The SDI is now organized into six program elements within the DOD. Figure 2 shows funding trends for these programs. A brief description of each element follows:

Surveillance, Acquisition, Tracking, and Kill Assessment (SATKA). This program element examines sensing technologies that would be needed to begin a defensive engagement, manage a battle, and assess the status of a ballistic missile attack. It includes a mixture of some of the most and least mature technologies being developed by the SDIO. It receives the largest portion of SDI funding. The most challenging task within SATKA appears to be developing the capability to discriminate among enemy warheads, decoys, and chaff in flight. The number of objects requiring identification could be in the tens of thousands during a full-scale nuclear attack.

Directed Energy Weapons (DEW). Directed energy weapons can in theory deliver destructive energy to targets at or near the speed of light. The purpose of this SDI effort is to explore their potential for BMD. The program element includes research on: high-power laser and particle beam generation; optics and sensors for correcting and controlling high-power beams; lightweight mirrors and magnets for focusing the beams on target; and fire control for delivering the required energy to a target. It examines four possible approaches to boost and post-boost BMD: space-based lasers; ground-based lasers with orbiting relay mirrors; space-based neutral particle beams; and charged particle beams for use in the atmosphere.

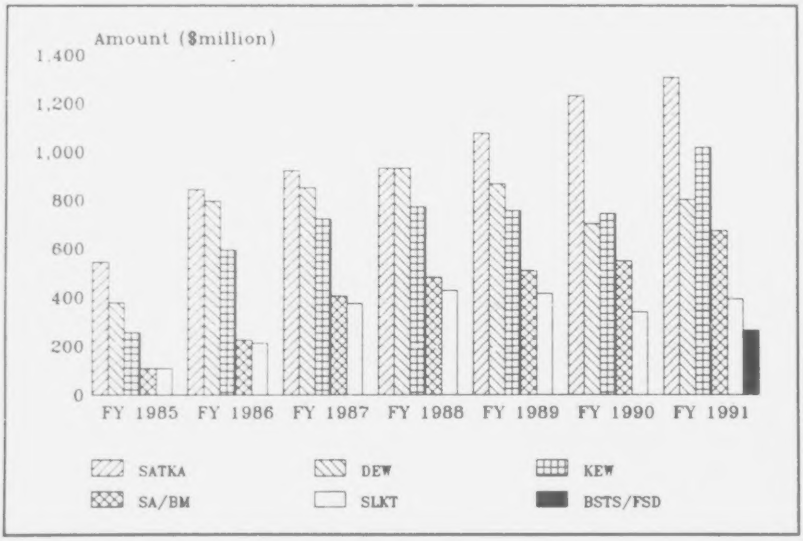
Currently, space-based chemical lasers are the most mature of these technologies. Funding for DEW projects has declined over the past few years.

Kinetic Energy Weapons (KEW). Kinetic energy weapons would be used to destroy their targets by impact rather than by explosion. This program element explores the potential use of conventional rockets and smart "hit-to-kill" weapons to render a ballistic missile or its warhead ineffective in any phase of its flight. Both ground-launched and spaced-based KEWs ("Brilliant Pebbles") are under investigation. They include some of the most mature technologies being developed under the SDI for near-term deployment options.

Survivability, Lethality, and Key Technologies (SLKT). This program element provides supporting research and technology development, seeking to ensure an effective SDI system and to satisfy various logistical requirements. It examines technologies for protecting an entire BMD system from a determined attack, seeking to predict the minimum energy required to destroy Soviet systems. It also includes research on space transportation, space power, on-orbit maintenance, and energy storage and conversion.

Systems Concepts and Battle Management (SC/BM). This program element seeks as its goal to develop the technologies needed for a highly responsive, very reliable, survivable, endurable, and cost-effective battle management/ command, control, and communication (C3) system. It also will develop and use modeling and simulation techniques to determine the technological risk and cost of developing such a system. This effort has been repeatedly characterized as the most difficult challenge facing the SDI program; funding has grown consistently since FY1985.

Figure 2
SDI RDT&E



Boost Surveillance and Tracking System/Full Scale Development (BSIS/FSD). This program is an orbiting surveillance system based on infrared technology that will seek to provide the capability to detect and track ballistic missiles during the first portion of their flight. In FY1991, the program will complete the demonstration and validation phase, then move to full-scale development.

Department of Energy

Although the SDI is often characterized as a nonnuclear effort, the Department of Energy (DOE) performs some nuclear energy research as part of the program. In February 1984, the Secretaries of Defense and Energy approved a joint policy statement clarifying the role of nuclear research in the SDI program. The document emphasizes that although the long-term goal of SDI is an effective nonnuclear defense, there are many reasons for including nuclear weapons research in the SDI program. These are:

- to determine the feasibility and effectiveness of nuclear-driven systems that the Soviets may develop for use against future U.S. defensive systems and satellites;
- to understand the technical feasibility and impact that Soviet nuclear-driven defensive systems might have on U.S. strategic offensive forces; and
- to explore nuclear-driven technologies, such as the X-ray laser, as possible U.S. options.

In July 1984, DOD and DOE approved a Memorandum of Agreement that provides for coordinating and integrating DOE's involvement in SDI research and for resolving potential disputes between the two agencies. The agreement established a steering committee to those ends, comprised of the SDI Director, the Deputy Secretary of Defense, and the Chairman of the Military Liaison Committee.

DOE's SDI-related research is carried out primarily by the three national nuclear laboratories: Los Alamos, Lawrence Livermore, and Sandia. Additional SDI-related work is conducted at these labs under contract to DOD. DOE is working on SDI in several areas, such as nuclear-directed energy concepts (e.g., x-ray laser) and SDI-related nuclear power research. Additionally, DOE is involved in several nonnuclear ballistic missile defense programs, including laser weapon concepts, at these labs. Both nuclear and nonnuclear research is being conducted into survivability and lethality problems. DOE is building a Strategic Defense Facility, to be located at Sandia National Laboratory, to conduct much of the experimental research on advanced defensive and directed energy concepts. SDI-DOE funding has been declining since 1986.

Soviet Strategic Defense Efforts

The scope and purpose of Soviet strategic defense efforts is unclear. The Reagan Administration asserted that Soviet efforts in most areas of strategic defense have long been far more extensive than those of the United States. Some officials insisted that the Soviets are some 10 years ahead of the United States in developing an SDI-type system. Other officials add that the Soviets have spent 10 to 15 times more on strategic defense than the United States has. More recently, Adm. Crowe, former Chairman of the Joint Chiefs of Staff, stated that such assertions may have been exaggerated. Nonetheless, the Bush Administration maintains that the Soviets have invested considerable resources to strategic defense.

The Reagan Administration's representations have included many more Soviet efforts than those programs being pursued under the SDI, thus making comparisons difficult. The following is a list of those Soviet programs included:

-- the Moscow ABM system (permitted by the ABM Treaty);
-- an extensive launch-detection satellite network and early warning network;
-- a network of new phased-array radars for ballistic missile detection and tracking (including the Krasnoyarsk radar, which the United States charges violates the ABM Treaty);
-- an operational antisatellite (ASAT) weapon, as well as research in other ASAT weapon technologies, including ground-based lasers;
-- development of computer and sensor technologies for advanced Soviet weapons programs;
-- modernization of strategic air defense forces (including 12,000 surface-to-air missile launchers, 10,000 air defense radars, 4,000 air defense interceptor aircraft, and an active program to improve Soviet air defense capabilities); and
-- passive defenses (including hardening of military facilities, such as underground command centers, fallout shelters, and programs to ensure the survivability of some offensive forces through mobility and hardening).

While these Soviet efforts are usually characterized as defensive, they are not fully comparable to the ballistic missile defense technologies being developed under the SDI program. Moreover, the intent, reliability, and capabilities of these Soviet efforts are hotly disputed. Many of the Soviet efforts cited above mirror non-SDI U.S. military programs, but others, such as continental air defense and civil defense, are no longer pursued in the United States. Consequently, some argue that it is not accurate to compare U.S. funding for SDI research with estimates of Soviet funding for programs covering a broader array of strategic defenses.

The Reagan Administration pointed to Soviet efforts that are analogous to SDI-managed programs, although there are no indications that the Soviets have formed their own "SDI" organization to bring all such efforts together. Some indication of where the United States and Soviet Union stood on comparative SDI efforts was presented to the Senate on Feb. 5, 1986, by Admiral James Crowe, Chairman of the Joint Chiefs of Staff. According to Crowe, the United States led in kinetic energy weapons, optical and infrared sensors and some radar technologies, electronic computers, and the maintenance of systems in space. There was rough equality in those directed energy weapons pursued in the SDI program and the ability to build heavy lift vehicles for space launches. The Soviets led in some types of laser research (which the Administration chooses not to pursue in SDI, but nonetheless asserts could have an ABM role) and in the integration of laser technologies into weapon devices, deployment of an operational kinetic energy ASAT weapon, some aspects of radar technology, optical computers, and space power supply. Crowe stated that the Defense Intelligence Agency could not provide a breakdown of costs of these Soviet efforts.

Key Issues

This section briefly examines some of the key SDI program-related issues of interest to the Congress.

Funding

What is the proper level of funding for the SDI program? The debate over the proper level of funding for the SDI program is generally unresolved at two levels. The first concerns the appropriate focus and direction of the program. The second concerns its pace.

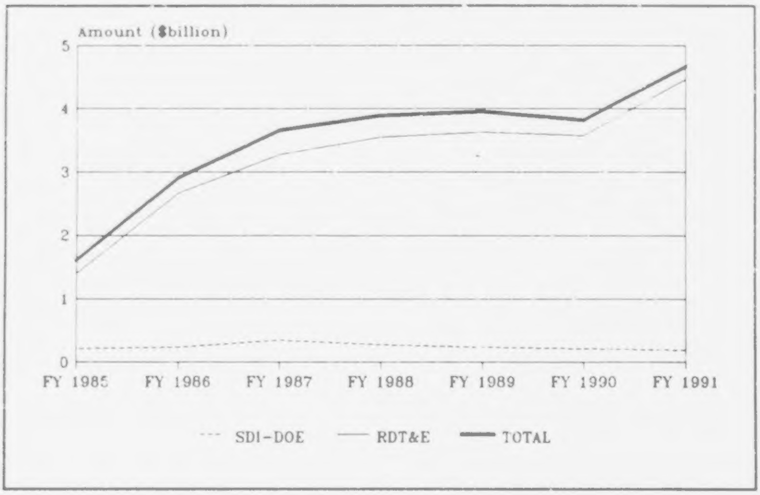
Currently, the SDI program embodies several objectives including: (1) to provide technical information that will make possible a knowledgeable decision on whether to deploy advanced ballistic missile defenses for various missions ranging from site to comprehensive nationwide defense; (2) to give the United States a hedge against Soviet advances in ballistic missile defense; and (3) to provide leverage for arms control negotiations with the Soviet Union.

Clearly, the less ambitious goal of using the program as a hedge would require less short-term funding than a program aimed at near-term deployment of any kind. Furthermore, if SDI is to pursue the first objective above, then program funding requirements would be greatly affected by the specific strategic defense options to be considered. For example, development of a near-term, ground-based defense of our national command authorities would lead to a much different program than development of a long-term, space- and ground-based defense of the population and infra-structure of the continental United States. The differences in these types of programs and their effective funding requirements would become more pronounced over time as research progresses to greater (presumably more expensive) levels of integration and testing. To the extent that multiple mission objectives are to be pursued, priorities among them will determine funding needs.

The architects of the SDI program originally conceived it to be a technology-limited, rather than fiscally-constrained, research and development program designed to progress as rapidly as the knowledge base would allow. The primary reason they adopted this philosophy was their belief that a strategic defense system eventually would be deployed in a competitive environment between the United States and the Soviet Union. In other words, Administration officials believed from the outset that the Soviet Union would work to counter the efforts of the SDI in an attempt to maintain their nuclear offensive threat to the United States. Thus, it was reasoned, to comply with President Reagan's vision of rendering nuclear weapons obsolete, the United States must jump out and stay ahead of the Soviet Union in strategic defense technologies.

Some supporters of this reasoning have argued that despite significant annual funding, congressional budget cuts of Administration requests have precluded a technology-limited program. Others contend that for a program of the magnitude and complexity of SDI, a "technology-limited" approach has no practical meaning. Some analysts and policymakers assumed that the President's request, by definition, represented what was needed for such a program. Given the current diversity of opinion within the Administration over program objectives, that assumption is questionable. Figure 3 illustrates the growth of SDI funding since 1985.

Figure 3
Total SDI Funding



Nonetheless, in a competitive environment, even a fiscally-constrained program must be conducted and funded to at least keep pace with the Soviets. However, the funding requirements for a fiscally-constrained SDI would be driven more by intelligence estimates of Soviet offensive and defensive efforts, than by the limits of our technical capabilities.

Two additional factors likely to affect funding requirements for SDI are the U.S. budget deficit and arms control negotiations. The deficit situation is exerting pressure on the Congress to reduce or slow the rate of funding for most Federal programs, including the SDI.

Arms control negotiations could affect SDI funding requirements in a number of ways. Possibilities that might reduce *near-term* funding requirements include agreements to: delay deployment beyond the 1990s; restrict testing; or preclude space-basing of weapons. Possible SDI-related arms negotiations developments that might increase the need for *near-term* funding include: an agreement to allow deployment of nationwide defenses beginning in the 1990s; or a deterioration of relations resulting in a strategic arms competition.

Should SDI be funded at an aggregate level? The DOD research, development, test, and evaluation (RDT&E) portion of the SDI budget is presented to Congress in the five program elements described earlier. Thus far, Congress has chosen to make general reductions to requested funding, leaving the specific program allocation to DOD. Several factors have lead to this approach, including recognition in the Congress that the potential of the various technologies being explored is not fully understood, and a belief that a research and development program should be conducted with a great deal of flexibility to allow the program director to take full advantage of unexpected results.

To a large extent, these factors continue to hold true. However, in the recent debate over mission objectives and decision timeliness, some Members have questioned the priorities for specific SDI projects. As a result, some exceptions have been made to the aggregate funding approach. As the debate over program objectives progresses, the tendency to specify project-level funding may increase.

Arms Control

What does the ABM Treaty mean for the SDI program? The ABM Treaty embodies a belief that the relationship between offensive nuclear weapons and strategic ballistic missile defenses (BMD) is highly complex and that when deployed together they can lead to strategic instability. The ABM Treaty purposefully restricted BMD deployment to a limited number of fixed, land-based ABM systems and components. Although deployment of effective and survivable SDI systems is Reagan's stated objective, it is not yet a reality. Many would therefore argue that ABM Treaty restrictions limiting SDI deployment are longer-term issues, to be resolved at some future point. In contrast, others would suggest that an SDI program intended to result in more than a limited deployment permitted by the Treaty should not be pursued, being seen as in contradiction to the ABM Treaty.

Even the development of a significant and effective BMD by either side was purposefully limited by the Treaty. Another key issue is to what extent does the ABM Treaty affect the pace and scope of the SDI program today. Here, what the ABM Treaty actually permits remains controversial. The traditional perspective holds that development, testing, and deployment of air-, sea-, space-, and mobile land-based ABM systems or components is prohibited. The Reagan Administration argues that a broader interpretation, which permits testing and development of ABM systems based on physical principles other than those in use in 1972 (regardless of basing mode), is fully justified. The Administration has not yet adopted this interpretation for the SDI test program, however.

The traditional or broad approach holds different implications for conducting the SDI program. Under the traditional perspective, the SDI program is challenged to devise a meaningful test program that does not provide an ABM capability, yet gives sufficient confidence that an effective ABM system could actually be built based on those test results.

Some supporters of a broader ABM Treaty interpretation believe that pursuing this traditional perspective leads to increased program cost and an essentially infeasible program. They argue that such tests are unrealistic, requiring additional treaty-compliant efforts. These people would argue instead that adoption of a broader Treaty interpretation, or withdrawal from the Treaty, is necessary to provide sufficient information whether to deploy SDI systems.

What role does SDI play in U.S.-Soviet arms control negotiations? Since early 1985, the United States and Soviet Union have sought to negotiate a strategic arms reduction treaty (START) in Geneva that would reduce each side's nuclear warheads by half. (See CRS Issue Brief 88088, Arms Control: Negotiations to Reduce Strategic Offensive Nuclear Weapons.) At the same time, they have sought to reach agreement on the issues of defense and space weapons. (See CRS Issue Brief 86073, Arms Control: Negotiations to Limit Space and Defense Weapons.)

Since 1985, there has been an impasse in the START negotiations, due largely to U.S. and Soviet differences over the SDI program. Some believe SDI is the reason why the Soviets began serious discussions of arms reductions and that SDI keeps them bargaining in good faith. Meanwhile, others assert that SDI is a major impediment to final agreement on a major arms accord.

While, the Administration argues that a major objective of the SDI program is to provide arms control leverage over the Soviet Union, it insists that SDI is not a bargaining chip, something to be traded away for Soviet concessions. More specifically, it is further argued that U.S. arms control leverage is increased because of the mere development of an option for phased deployment of strategic defense, thus helping to motivate Soviet acceptance of U.S. arms reduction proposals.

Are SDI and strategic arms control compatible? A more fundamental question is whether SDI and strategic arms control can coexist. While SDI is solely a long-term research program, without specific deployment goals beyond those permitted by treaty, SDI compatibility with arms control is less fiercely contested.

Some argue that SDI poses a clear threat to the future of arms control, at least at the strategic weapons level. The SDI program, it is argued, will lead to either the gradual erosion of the ABM Treaty (because of the interpretation controversy and scheduled SDI tests) or its eventual abrogation (because of momentum toward SDI's deployment). Many view the ABM Treaty as having prevented an expensive and dangerous offensive-defensive strategic nuclear arms race. They further argue that SDI blocks any possibility of achieving a strategic nuclear arms reduction agreement with the Soviets. Fearing that SDI will eventually lead to the deployment of comprehensive ABM systems, the Soviets will choose to develop and deploy more offensive strategic nuclear weapons at less cost to defeat any SDI system. They will therefore have no incentive to agree to reductions in offensive arms, according to this perspective.

Others counter that U.S. acceptance of the ABM Treaty in 1972 was conditional. The Treaty assumed there would be follow-on agreements to reduce substantially the numbers of offensive nuclear weapons, so that with acceptance of defensive constraints, offensive nuclear capabilities would not be able to threaten a successful "first-strike." U.S. land-based strategic forces are viewed as vulnerable partly because of the unconstrained growth in Soviet offensive capabilities. In this context, deployment of a limited SDI system resolves the problem of U.S. ICBM vulnerability, while building the foundation for more comprehensive arms reduction efforts.

As indicated earlier, the Reagan Administration argued that SDI holds the key to eliminating the threat posed by strategic nuclear ballistic missiles by either compelling the Soviets to reduce their nuclear weapons, thus fulfilling the purposes of arms control or by eventually neutralizing them. In this context, SDI is not only seen as compatible with arms control, but necessary to produce an effective arms reduction agreement.

LEGISLATION

FY1990. The Bush Administration reduced the original FY1990 Reagan Administration request by about $1 billion to $4.88 billion ($4.6 billion for RDT&E, $11 million for military construction, and $266 million for DOE-SDI related programs.)

Congress authorized $3.8 billion ($3.57 billion for RDT&E, $6 million for military construction, and $220 million for SDI-DOE programs). As in previous years, Congress approved legislation prohibiting development or testing inconsistent with the proposed activities found in the annual SDI report to Congress; this is generally understood to support the narrow or traditional interpretation of the ABM Treaty.

FY1991. The Bush Administration requested $4.7 billion for SDI ($4.5 billion for RDT&E, $11 million for military construction, and $192 million for SDI-DOE programs).

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APPENDIX

SDI Funding Data
(In $ Millions)

	FY1985 a/	FY1986	FY1987	FY1988	FY1989	FY1990	FY1991 Request
RDT&E:							
SATKA	$546.00	$844.00	$923.00	$934.50	$1,1076.50	$1,232.20	$1,306.70
DEW	$378.00	$796.00	$853.10	$934.30	$867.50	$703.30	$802.90
KEW	$256.00	$596.00	$722.50	$773.20	$757.60	$744.60	$1,017.70
SA/BM	$100.30	$212.40	$385.80	$461.50	$485.80	$550.00 b/	$674.00 b/
SLKT	$108.40	$214.00	$375.30	$429.60	$415.80	$341.00	$393.60
BSTS/FSD	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$265.00
SDIO HQ	$9.10	$12.70	$20.00	$20.00	$24.20	$0.00	$0.00
Total RDT&E	**$1,397.80**	**$2,675.10**	**$3,279.70**	**$3,553.10**	**$3,627.40**	**$3,571.10**	**$4,459.90**
MILCON	$0.00	$3.10	$28.50	$59.20	$83.00	$33.50 c/	$11.40
Total DOD	**$1,397.80**	**$2,678.20**	**$3,308.20**	**$3,612.30**	**$3,710.40**	**$3,604.60**	**$4,471.30**
DOE SDIO	$215.00	$235.10	$349.00	$279.00	$240.30	$214.40	$191.90
Total SDI	**$1,612.80**	**$2,913.30**	**$3,657.20**	**$3,891.30**	**$3,950.70**	**$3,819.00**	**$4,663.20**

a/ FY1985 was the first year of funding for the Strategic Defense Initiative. Prior to this, ballistic missile defense research and development programs were funded through the various military services and defense agencies.

b/ Includes SDIO management costs previously shown in SDIO HQ program elements.

c/ Includes $23 million reprogramming for National Test Facility.

Reproduced from Ethical and Religious Aspects of SDI: Pro and Con, by
Charles H. Whittier, Specialist in Religion and Public Policy.
Washington, Congressional Research Service, 1987. 4 p.
(CRS Report for Congress 87-535 GOV)

ETHICAL AND RELIGIOUS ASPECTS OF SDI: PRO AND CON

Ethical, moral, and religious dimensions of the Strategic Defense Initiative (SDI) involve a complex interplay between political and metapolitical questions--the realm of power politics and the realm of value. Moreover, these realms are themselves bound up with the problem of appropriate and necessary technology in research and development and the issue of their cost in relation to the allocation of resources and energies.

Those who oppose the SDI proposals on ethical grounds tend generally to base their arguments on two crucial points: feasibility and actual effect. That is--are the proposals feasible, particularly in terms of technological development and social cost, and will they, in fact, provide reasonable assurance of success in attaining the goal of defensive security. Opponents hold that the total cost is unpredictable, that no overall security system is infallible and that the social burden of the program would be wasteful and vastly excessive in light of human needs that could be met with the resources alternatively employed. They contend that the effect of SDI would be to intensify the arms race and dangerously destabilize the present situation. For those who hold this position, both feasibility and effect touch upon essentially ethical or moral issues--the preservation of peace between the superpowers and the rightful or just allocation of domestic resources to perceived social needs. Some who oppose SDI favor alternative proposals for arms control or disarmament. Others oppose any use of nuclear arms as immoral

NOTE

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in itself, given the nature of nuclear weapons and the dangers of acceleration inherent in even limited use. Still others oppose even the threat of use, arguing that fundamental principles of the just war tradition (proportionality of ends and means, and noncombatant immunity) are inevitably violated in nuclear warfare.

Many who oppose SDI, citing these and similar arguments, emphasize that their position is grounded in a perceived Scriptural mandate to seek peace. They tend to regard SDI as harmful in that its effect would be to aggravate the arms race, to heighten suspicion and tension between the powers, and to create the illusion of total security in the West while risking a Soviet preemptive first-strike. They stress what they perceive as the offensive implications of the "defensive shield" and its negative impact on anti-ballistic missile agreements, and the actual effect of "counter-force targeting" when the targets are within or near heavily urban areas.

Opponents of SDI are divided over the question of deterrence. Some argue that deterrence is not inherently immoral but dangerous in its reliance upon the ultimate rationality of both sides. Others accept a limited role for deterrence or the threat implicit in it as a temporary necessity while moving toward disarmament. They hold that this is more ethically responsible than the SDI proposal.

Finally, some who oppose SDI do so not from prudential ethics but from an absolute pacifism, rejecting all forms of coercion or violence. Often they cite the ethic of nonviolence in the Gospels and in other world religious literature.

Those who support SDI tend generally to argue that it is morally superior to the doctrine of deterrence (mutual assured destruction or mutual vulnerability) because of its essentially defensive character. They hold that it would provide effective homeland defense and that it is a system that destroys offensive weapons, not people. In this view, a system that attempts to keep the peace by assuring the mutual destruction of contending societies in the event of a breach of peace is morally abhorrent. Some supporters of SDI would share the technology when it matures so that balanced effective defenses would make nuclear attack mutually uninviting. Others would seek the stability of U.S. strategic superiority through SDI. They emphasize that the underlying conflict between the superpowers has an ethical or moral dimension and that the West has an obligation to protect the religious, philosophical and personal liberties associated with its social and economic system from totalitarian Soviet encroachment; hence, the desirability of SDI, providing an assured security while reducing or even eliminating (through selective counterforce-targeting) the threat to noncombatant populations.

Proponents emphasize the scale and intensity of technological development and innovation in the past, argue that the West can achieve the needed technology for SDI and that it should do so before the Soviets are able to, and note that estimates of cost at this time are speculative. They also cite the numerous perceived side-benefits that would flow from the technological aspects of the program.

In arguing that SDI is feasible in technology and in cost and attainable as a national defense goal, many proponents grant that no full-scale defense system can be entirely effective. They emphasize, however, that commitment to the program will assure a reasonable measure of homeland security and reduce the dangers in deterrence. Many base these and similar arguments on the just war tradition in Christian history and the appeal to the right to act in self-defense, a right articulated by such major figures at St. Augustine and St. Thomas Aquinas. Some proponents hold that SDI is more compatible with ethical and moral ideals then are other proposals because of its emphasis upon defense as against first-strike or massive retaliatory offense. Many maintain that the values embodied in the West as well as peace between the superpowers will be better preserved by SDI and its promise of assured ascendancy through strategic defense.

Opponents and proponents alike employ ethical and religious, including biblically-based, arguments. Many who oppose SDI also tend to oppose deterrence (mutual assured destruction) except as an interim policy while arms control is explored, basing this position on an ethic of peace, grounded (for some) in a theology of peace that includes renunciation and eventual dismantling of all nuclear weapons through arms control negotiations. Many who support SDI also reject deterrence, arguing, on the basis of a prudential ethic, grounded (for some)in a theological perspective, that common security for the West will be better achieved through strategic defense. 1/

1/ See, for contending views, A Pastoral Letter to All United Methodists, "In Defense of Creation; the Nuclear Crisis, and a Just Peace", issued by the Council of Bishops of the United Methodist Church. April 29, 1986; and Weigel, George. "Breaking the Doctrinal Gridlock--Common Security and the Strategic Defense Initiative." This World. Winter. 1987. No. 16. p. 3-22.

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Reproduced from the United Nations General Assembly and Disarmament 1986. New York, United Nations Department for Disarmament Affairs, 1987. p. 170-177.

PREVENTION OF AN ARMS RACE IN OUTER SPACE

Res. 41/53 - "Prevention of an arms race in outer space"

Because of divergent approaches to the question, four draft resolutions, all entitled "Prevention of an arms race in outer space", were submitted to the First Committee, three of which were not put to a vote.

On 27 October, China submitted the first draft resolution, which it introduced on 5 November. China stated that the trend towards expanding the arms race to outer space had been continuously growing. It noted that it would be much more difficult to reach agreements on limiting or banning space weapons once such weapons were deployed. Therefore, preventing an arms race in outer space had become a most pressing task. By the draft, the General Assembly would request the Conference on Disarmament to speed up its consideration of the question of the prevention of an arms race in outer space and to re-establish without delay an ad hoc committee on the item at the outset of its 1987 session. In addition, the draft called upon all States possessing outer space capabilities to refrain from developing, testing and deploying outer space weapons, so as to create propitious conditions for negotiations.

On 29 October, 16 mainly non-aligned States[1] submitted the second draft resolution on outer space. In introducing it on 3 November, Sri Lanka stated that the draft reflected the mainstream of the thinking of non-aligned and neutral countries and reiterated the basic principles set out in the Harare Political Declaration[2] of the heads of State or Government of the non-aligned countries and the Mexico Declaration[3] of the six countries of the five-continent peace initiative. It was a consistent principle of the non-aligned States that disarmament issues were the concern of all States and that bilateral negotiations, while welcome in themselves, did not diminish the need for multilateral negotiations. In conclusion, Sri Lanka stated that the sponsors of the draft were ready to hold discussions with the sponsors of the other drafts submitted on the same subject in order to achieve a consensus resolution which would send out an honest and universally acceptable message that weapons would not be introduced into space.

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[1] Algeria, Argentina, Bangladesh, Brazil, Egypt, Ethiopia, India, Indonesia, Mexico, Nigeria, Pakistan, Romania, Sri Lanka, Sudan, Yugoslavia and Zimbabwe.

On 30 October, nine socialist States[4] submitted the third draft resolution on the subject. The draft called upon all States, in particular those with major space capabilities, to contribute actively to the objective of the peaceful use of outer space and to adhere strictly to the existing legal restrictions and limitations on space weapons, including those contained in the 1967 outer space Treaty and the 1972 anti-ballistic missile (ABM) Treaty; reiterated that the Conference on Disarmament had the primary responsibility in the negotiation of a multilateral agreement, or agreements, as appropriate, on the prevention of an arms race in outer space in all its aspects; and requested the Conference to intensify its consideration of the question and to re-establish an ad hoc committee on the prevention of an arms race in outer space at the beginning of its 1987 session.

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[2] A/41/697-S/18392, annex.

[3] A/41/518-S/18277, annex I.

[4] Bulgaria, Byelorussian SSR, Czechoslovakia, German Democratic Republic, Hungary, Mongolia, Poland, Ukrainian SSR and USSR.

The same day, 11 mainly Western States[5] submitted the fourth draft resolution, which Italy introduced on 5 November. Italy stated that arms-control issues related to the military use of space had a significant bearing on international stability and, therefore, were of great relevance for international peace and security. The sponsors of the draft believed that, to facilitate agreement that would really enhance strategic stability, issues concerning nuclear and space arms should be considered in their interrelationship. They hoped that recent developments in the negotiations between the Soviet Union and the United States would bring about progress. At the same time, they were convinced that the multilateral and bilateral negotiating processes were mutually complementary. Accordingly, the draft called upon the Soviet Union and the United States to intensify their negotiations in the search for effective and verifiable bilateral agreements and reiterated that the Conference on Disarmament had a primary role to play in the question of preventing an arms race in outer space.

On 14 November, the original sponsors of the draft introduced by Sri Lanka, plus 4 additional States, submitted a revised draft resolution which was later sponsored by another 4 States.[6] On 17 November the First Committee voted on the revised draft resolution. A separate vote was taken on operative paragraph 8 (see below), which was approved by a recorded vote of 116 to 1 (United States), with 12 abstentions (Western and associated countries). Thereupon the Committee approved the revised draft resolution, as a whole, by a recorded vote of 130 to none, with 1 abstention (United States).

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[5] Belgium, Canada, Germany, Federal Republic of, Iceland, Italy, Japan, Netherlands, Norway, Portugal, Turkey and United Kingdom.

[6] Cameroon, China, Czechoslovakia, German Democratic Republic, Ireland, Peru, Sweden and Venezuela.

In connection with the vote, China, the Soviet Union and Italy informed the Committee that they no longer insisted on a vote on the drafts they had introduced and stated that they were pleased that there would be a single draft on the issue.

Speaking on behalf of a group of eight countries,[7] Italy stated that they supported the general thrust of the revised text, although many aspects did not fully reflect their thinking on the issue. They abstained in the vote on operative paragraph 8 because, in their view, it did not take into account the importance of the substantive discussions in the Conference on Disarmament. Indeed, it believed that the wording of that paragraph tended to prejudge the outcome of those discussions.

The United States explained that it had voted against operative paragraph 8 because it did not believe that, at that time, there was a basis for multilateral negotiations on outer space arms control. It also objected to the reference in the revised draft to the Harare Declaration, which, in its view, was one-sided and biased on vital security and disarmament issues. It believed that such a document should not be accorded a status comparable to that of General Assembly resolutions. In conclusion, the United States noted with satisfaction the work accomplished in 1986 by the Conference on Disarmament and its Ad Hoc Committee on outer space and hoped that the Committee would continue its work in 1987 under its existing mandate.

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[7] Belgium, France, Germany, Federal Republic of, Italy, Japan, Luxembourg, Netherlands and United Kingdom.

Australia regretted that despite serious efforts it had not been possible to arrive at a single consensus resolution on the subject. It nevertheless was grateful to the sponsors that had withdrawn their drafts and hoped that consensus would be reached at the forty-second session. It voted in favour of operative paragraph 8 and the revised draft resolution as a whole because of the importance it attached to the need to prevent an arms race in outer space and its belief that practical measures in that field were a matter of considerable urgency.

On 3 December the General Assembly voted on the revised draft resolution. Operative paragraph 8 of the draft was adopted by a recorded vote of 140 to 1, with 12 abstentions. The draft resolution as a whole was adopted by a recorded vote of 154 to none, with 1 abstention, as resolution 41/53. It reads as follows:

The General Assembly,

Inspired by the great prospects opening up before mankind as a result of man's entry into outer space,

Recognizing the common interest of all mankind in the exploration and use of outer space for peaceful purposes,

Reaffirming that the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interest of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind,

Reaffirming further the will of all States that the exploration and use of outer space, including the Moon and other celestial bodies, shall be for peaceful purposes,

Recalling that the States parties to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, have undertaken, in article III, to carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law and the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding, Reaffirming, in particular, article IV of the above-mentioned Treaty, which stipulates that States parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies or station such weapons in outer space in any other manner,

Reaffirming also paragraph 80 of the Final Document of the Tenth Special Session of the General Assembly, the first special session devoted to disarmament, in which it is stated that, in order to prevent an arms race in outer space, further measures should be taken and appropriate international negotiations held in accordance with the spirit of the Treaty,

Recalling its resolutions 36/97 C and 36/99 of 9 December 1981, as well as resolutions 37/83 of 9 December 1982, 37/99 D of 13 December 1982, 38/70 of 15 December 1983, 39/59 of 12 December 1984 and 40/87 of 12 December 1985 and the relevant paragraphs of the Political Declaration of the Eighth Conference of Heads of State or Government of Non-Aligned Countries, held at Harare from 1 to 6 September 1986,

Gravely concerned at the danger posed to all mankind by an arms race in outer space and, in particular, by the impending threat of the exacerbation of the current state of insecurity by developments that could further undermine international peace and security and retard the pursuit of general and complete disarmament,

Mindful of the widespread interest expressed by Member States in the course of the negotiations on and following the adoption of the above-mentioned Treaty in ensuring that the exploration and use of outer space should be for peaceful purposes, and taking note of proposals submitted to the General Assembly at its tenth special session and at its regular sessions and to the Conference on Disarmament,

Noting the grave concern expressed by the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space at the extension of an arms race into outer space and the recommendations made to the competent organs of the United Nations, in particular the General Assembly, and also to the Committee on Disarmament,

Convinced that further measures are urgently needed for the prevention of an arms race in outer space,

Recognizing that, in the context of multilateral negotiations for preventing an arms race in outer space, bilateral negotiations between the Union of Soviet Socialist Republics and the United States of America could make a significant contribution to such an objective, in accordance with paragraph 27 of the Final Document of the Tenth Special Session of the General Assembly,

Noting with satisfaction that bilateral negotiations between the Union of Soviet Socialist Republics and the United States of America have continued since 1985 on a complex of questions concerning space and nuclear arms, both strategic and intermediate-range, and on their relationship, with the declared objective, endorsed in the joint statement of their leaders on 21 November 1985, of working out effective agreements aimed, inter alia, at preventing an arms race in outer space,

Anxious that concrete results should emerge from these negotiations as soon as possible,

Taking note of the part of the report of the Conference on Disarmament relating to this question,

Welcoming the re-establishment of an Ad Hoc Committee on the prevention of an arms race in outer space during the 1986 session of the Conference on Disarmament, in the exercise of the negotiating responsibilities of this sole multilateral negotiating body on disarmament, to continue to examine and to identify through substantive and general consideration issues relevant to the prevention of an arms race in outer space,

1. Recalls the obligation of all States to refrain from the threat or use of force in their space activities;

2. Reaffirms that general and complete disarmament under effective international control warrants that outer space shall be used exclusively for peaceful purposes and that it shall not become an arena for an arms race;

3. Emphasizes that further measures with appropriate and effective provisions for verification to prevent an arms race in outer space should be adopted by the international community;

4. Calls upon all States, in particular those with major space capabilities, to contribute actively to the objective of the peaceful use of outer space and to take immediate measures to prevent an arms race in outer space in the interest of maintaining international peace and security and promoting international co-operation and understanding;

5. Reiterates that the Conference on Disarmament, as the single multilateral disarmament negotiating forum, has the primary role in the negotiation of a multilateral agreement or agreements, as appropriate, on the prevention of an arms race in outer space in all its aspects;

6. Requests the Conference on Disarmament to consider as a matter of priority the question of preventing an arms race in outer space;

7. Also requests the Conference on Disarmament to intensify its consideration of the question of the prevention of an arms race in outer space in all its aspects, taking into account all relevant proposals including those presented in the Ad Hoc Committee on the prevention of an arms race in outer space at the 1986 session of the Conference and at the forty-first session of the General Assembly;

8. Further requests the Conference on Disarmament to re-establish an ad hoc committee with an adequate mandate at the beginning of its 1987 session, with a view to undertaking negotiations for the conclusion of an

agreement or agreements, as appropriate, to prevent an arms race in outer space in all its aspects;

9. Urges the Union of Soviet Socialist Republics and the United States of America to pursue intensively their bilateral negotiations in a constructive spirit aimed at reaching early agreement for preventing an arms race in outer space, and to advise the Conference on Disarmament periodically of the progress of their bilateral sessions so as to facilitate its work;

10. Calls upon all States, especially those with major space capabilities, to refrain, in their activities relating to outer space, from actions contrary to the observance of the relevant existing treaties or to the objective of preventing an arms race in outer space;

11. Requests the Secretary-General to convey to the Advisory Board on Disarmament Studies, in its capacity as the Board of Trustees of the United Nations Institute for Disarmament Research, the wish of the Member States for the early completion of the Institute's study on disarmament problems relating to outer space and the consequences of extending the arms race into outer space;

12. Requests the Conference on Disarmament to report on its consideration of this subject to the General Assembly at its forty-second session;

13. Requests the Secretary-General to transmit to the Conference on Disarmament all documents relating to the consideration of this subject by the General Assembly at its forty-first session;

14. Decides to include in the provisional agenda of its forty-second session the item entitled "Prevention of an arms race in outer space".

58. Prevention of an arms race in outer space

This item was included in the agenda of the thirty-sixth session of the General Assembly, in 1981, at the request of the Union of Soviet Socialist Republics (A/36/192). At that session, the Assembly considered it necessary to take effective steps, by concluding an appropriate international treaty, to prevent the spread of the arms race to outer space; and requested the Committee on Disarmament to embark on negotiations with a view to achieving agreement on the text of such a treaty (resolution 36/99).

80/ References for the forty-third session (agenda item 58):

(a) Report of the Conference on Disarmament: Supplement No. 27 (A/43/27);

(b) Report of the First Committee: A/43/837;

(c) Resolution 43/69;

(d) Meetings of the First Committee: A/C.1/43/PV.3-43;

(e) Plenary meeting: A/43/PV.73.

At its thirty-seventh session, the General Assembly reaffirmed the will of all States that outer space should be used exclusively for peaceful purposes and that it should not become an arena for an arms race; declared that any use other than for exclusively peaceful purposes ran counter to the agreed objective of general and complete disarmament under effective international control; emphasized that further effective measures to prevent an arms race in outer space should be adopted by the international community; called upon all States, in particular those with major space capabilities, to contribute actively to the objective of the peaceful use of outer space and to take immediate measures to prevent an arms race in outer space; and requested the Committee on Disarmament to consider as a matter of priority the question of preventing an arms race in outer space and to establish an ad hoc working group on the subject at the beginning of its session in 1983, with a view to undertaking negotiations for the conclusion of an agreement or agreements, as appropriate, to prevent an arms race in all its aspects in outer space (resolution 37/83).

At its thirty-eighth to forty-second sessions, the General Assembly continued its consideration of the item (resolutions 38/70, 39/59, 40/87, 41/53 and 42/33).

At its forty-third session, 81/ the General Assembly reaffirmed that general and complete disarmament under effective international control warranted that outer space should be used exclusively for peaceful purposes and that it should not become an arena for an arms race; recognized, as stated in the report of the Ad Hoc Committee of the Conference on Disarmament, that the legal régime applicable to outer space by itself did not guarantee the prevention of an arms race in outer space, that this legal régime played a significant role in the prevention of an arms race in that environment, the need to consolidate and reinforce that régime and enhance its effectiveness, and the importance of strict compliance with existing agreements, both bilateral and multilateral; emphasized that further measures with appropriate and effective provisions for verification to prevent an arms race in outer space should be adopted by the international community; called upon all States, in particular those with major space capabilities, to contribute

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81/ References for the forty-third session (agenda item 59):

(a) Report of the Conference on Disarmament: Supplement No. 27 (A/43/27);

(b) Report of the Secretary-General: A/43/506 and Corr.1 and Add.1 and 2;

(c) Report of the First Committee: A/43/838;

(d) Resolution 43/70;

(e) Meetings of the First Committee: A/C.1/43/PV.3-25 and 42;

(f) Plenary meeting: A/43/PV.73.

Reproduced from Prevention of an Arms Race in Outer Space in Annotated Preliminary list of items to be included in the provisional agenda of the forty-fourth regular session of the General Assembly. New York, United Nations, 1989. p. 156-158.

actively to the objective of the peaceful use of outer space and to take immediate measures to prevent an arms race in outer space in the interest of maintaining international peace and security and promoting international co-operation and understanding; reiterated that the Conference on Disarmament, as the single multilateral disarmament negotiating forum, had the primary role in the negotiation of a multilateral agreement or agreements, as appropriate, on the prevention of an arms race in outer space in all its aspects; requested the Conference on Disarmament to consider as a matter of priority the question of preventing an arms race in outer space; also requested the Conference to intensify its consideration of the question of the prevention of an arms race in outer space in all its aspects, taking into account all relevant proposals and initiatives including those presented in the Ad Hoc Committee at the 1988 session of the Conference and at the forty-third session of the General Assembly; further requested the Conference to re-establish an ad hoc committee with an adequate mandate at the beginning of its 1989 session, with a view to undertaking negotiations for the conclusion of an agreement or agreements, as appropriate, to prevent an arms race in outer space in all its aspects; urged the Union of Soviet Socialist Republics and the United States of America to pursue intensively their bilateral negotiations in a constructive spirit aimed at reaching early agreement for preventing an arms race in outer space, and to advise the Conference on Disarmament periodically of the progress of their bilateral sessions so as to facilitate its work; called upon all States, especially those with major space capabilities, to refrain, in their activities relating to outer space, from actions contrary to the observance of the relevant existing treaties or to the objective of preventing an arms race in outer space; took note of the report of the Secretary-General on the question of the prevention of an arms race in outer space submitted in accordance with resolution 42/33 of 30 November 1987; requested the Conference on Disarmament to report on its consideration of this subject to the Assembly at its forty-fourth session; and requested the Secretary-General to transmit to the Conference on Disarmament all documents relating to the consideration of this subject by the Assembly at its forty-third session (resolution 43/70).

Document: Report of the Conference on Disarmament, Supplement No. 27 (A/44/27).

44/112. *Prevention of an arms race in outer space*

Date: 15 December 1989 Meeting: 81
Vote: 153-1-0 (recorded) Report: A/44/780

The General Assembly,

Inspired by the great prospects opening up before mankind as a result of man's entry into outer space,

Recognizing the common interest of all mankind in the exploration and use of outer space for peaceful purposes,

Reaffirming that the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interest of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind,

Reaffirming also the will of all States that the exploration and use of outer space, including the Moon and other celestial bodies, shall be for peaceful purposes,

Recalling the obligation of all States, in accordance with the Charter of the United Nations, to refrain from the threat or use of force, including in their space activities,

Recalling that the States parties to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies 40/ have undertaken, in article III, to carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law and the Charter of the United Nations, in the interests of maintaining international peace and security and promoting international co-operation and understanding,

Reaffirming, in particular, article IV of the above-mentioned Treaty, which stipulates that States parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies or station such weapons in outer space in any other manner,

Reaffirming also paragraph 80 of the Final Document of the Tenth Special Session of the General Assembly, 41/ in which it is stated that in order to prevent an arms race in outer space further measures should be taken and appropriate international negotiations held in accordance with the spirit of the Treaty,

Noting its resolutions 36/97 C and 36/99 of 9 December 1981, as well as resolutions 37/83 of 9 December 1982, 37/99 D of 13 December 1982, 38/70 of 15 December 1983, 39/59 of 12 December 1984, 40/87 of 12 December 1985, 41/53 of 3 December 1986, 42/33 of 30 November 1987 and 43/70 of 7 December 1988 and the relevant paragraphs of the Declaration adopted by the Ninth Conference of Heads of State or Government of the Movement of Non-Aligned Countries, held at Belgrade from 4 to 7 September 1989, 42/

Recognizing the importance and urgency of preventing an arms race in outer space and the readiness of all States to contribute to that common objective,

Gravely concerned at the danger posed to all mankind by an arms race in outer space and, in particular, by developments that could further undermine international peace and security and retard the pursuit of general and complete disarmament,

Encouraged by the widespread interest expressed by Member States in the course of negotiations on and following the adoption of the above-mentioned Treaty in ensuring that the exploration and use of outer space should be for peaceful purposes, and taking note of proposals submitted to the General Assembly at its tenth special session and at its regular sessions and to the Conference on Disarmament,

Noting the grave concern expressed by the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space at the extension of an arms race into outer space and the recommendations 43/ made to the competent organs of the United Nations, in particular the General Assembly, and also to the Committee on Disarmament, 44/

40/ Resolution 2222 (XXI), annex.

41/ Resolution S-10/2.

42/ See A/44/551-S/20870, annex.

43/ See *Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 9-21 August 1982* (A/CONF.101/10 and Corr.1 and 2), para. 426.

44/ The Committee on Disarmament was redesignated the Conference on Disarmament as from 7 February 1984.

Reproduced from Prevention of an Arms Race in Outer Space in Resolutions and Decisions Adopted by the General Assembly during the first part of its Forty-Fourth Session, from 19 September to 29 December 1989; Press Release. New York, United Nations Department of Public Information, 1989. p. 107-110.

Noting also that in 1989 the *Ad Hoc* Committee on the Prevention of an Arms Race in Outer Space, taking into account its previous efforts since its establishment, undertook the examination and identification of various issues, existing agreements and existing proposals, as well as future initiatives relevant to the prevention of an arms race in outer space, 45/ and that this contributed to a better understanding of a number of problems and to a clearer perception of the various positions,

Convinced that additional measures should be examined in the search for effective and verifiable bilateral and multilateral agreements in order to prevent an arms race in outer space,

Emphasizing the paramount importance of strict compliance with existing arms limitation and disarmament agreements relevant to outer space, and with the existing legal régime concerning the use of outer space,

Emphasizing also the necessity of maintaining the effectiveness of relevant existing treaties, and, in this context, reaffirming the vital importance of a strict compliance with the Treaty on the Limitation of Anti-Ballistic Missile Systems, 46/

Recognizing that bilateral negotiations between the United States of America and the Union of Soviet Socialist Republics could facilitate the multilateral negotiations for the prevention of an arms race in outer space in accordance with paragraph 27 of the Final Document of the Tenth Special Session of the General Assembly,

Noting the importance in this context of bilateral negotiations between the Union of Soviet Socialist Republics and the United States of America that have continued since 1985, including at their summit meetings in Washington, D.C. and Moscow on a complex of questions concerning space and nuclear arms,

Hopeful that concrete results would emerge from these negotiations as soon as possible,

Emphasizing the mutually complementary nature of bilateral and multilateral efforts in the field of preventing an arms race in outer space,

Taking note of that part of the report of the Conference on Disarmament relating to this question, 47/

Welcoming the re-establishment of an *Ad Hoc* Committee on the Prevention of an Arms Race in Outer Space during the 1989 session of the Conference on Disarmament, in the exercise of the negotiating responsibilities of this sole multilateral negotiating body on disarmament, to continue to examine and to identify, through substantive and general consideration, issues relevant to the prevention of an arms race in outer space,

1. *Reaffirms* that general and complete disarmament under effective international control warrants that outer space shall be used exclusively for peaceful purposes and that it shall not become an arena for an arms race;

2. *Recognizes*, as stated in the report of the *Ad Hoc* Committee of the Conference on Disarmament, that the legal régime applicable to outer space by itself does not guarantee the prevention of an arms race in outer space, that this legal régime plays a significant role in the prevention of an arms race in that environment, the need to consolidate and reinforce that régime and enhance its effectiveness, and the importance of strict compliance with existing agreements, both bilateral and multilateral; 48/

3. *Emphasizes* that further measures with appropriate and effective provisions for verification to prevent an arms race in outer space should be adopted by the international community;

4. *Calls upon* all States, in particular those with major space capabilities, to contribute actively to the objective of the peaceful use of outer space and to take immediate measures to prevent an arms race in outer space in the interest of maintaining international peace and security and promoting international co-operation and understanding;

5. *Reiterates* that the Conference on Disarmament, as the single multilateral disarmament negotiating forum, has the primary role in the negotiation of a multilateral agreement or agreements, as appropriate, on the prevention of an arms race in outer space in all its aspects;

6. *Requests* the Conference on Disarmament to consider as a matter of priority the question of preventing an arms race in outer space;

45/ See *Official Records of the General Assembly, Forty-fourth Session, Supplement No. 27* (A/44/27), para. 90.

46/ United Nations, *Treaty Series*, vol. 944, No. 13466.

47/ *Official Records of the General Assembly, Forty-fourth Session, Supplement No. 27* (A/44/27), sect. III.E.

48/ *Ibid*., para. 90 (para. 77 of the quoted text).

7. *Also requests* the Conference on Disarmament to intensify its consideration of the question of the prevention of an arms race in outer space in all its aspects, taking into account relevant proposals and initiatives, including those presented in the *Ad Hoc* Committee at the 1989 session of the Conference and at the forty-fourth session of the General Assembly;

8. *Further requests* the Conference on Disarmament to re-establish an *ad hoc* committee with an adequate mandate at the beginning of its 1990 session, with a view to undertaking negotiations for the conclusion of an agreement or agreements, as appropriate, to prevent an arms race in outer space in all its aspects;

9. *Urges* the Union of Soviet Socialist Republics and the United States of America to pursue intensively their bilateral negotiations in a constructive spirit aimed at reaching early agreement for preventing an arms race in outer space, and to advise the Conference on Disarmament periodically of the progress of their bilateral sessions so as to facilitate its work;

10. *Calls upon* all States, especially those with major space capabilities, to refrain, in their activities relating to outer space, from actions contrary to the observance of the relevant existing treaties or to the objective of preventing an arms race in outer space;

11. *Takes note* of the report of the Secretary-General on the question of the prevention of an arms race in outer space, 49/ submitted in accordance with resolution 42/33 of 30 November 1987;

12. *Requests* the Conference on Disarmament to report on its consideration of this subject to the General Assembly at its forty-fifth session;

13. *Requests* the Secretary-General to transmit to the Conference on Disarmament all documents relating to the consideration of this subject by the General Assembly at its forty-fourth session;

14. *Decides* to include in the provisional agenda of its forty-fifth session the item entitled "Prevention of an arms race in outer space".

RECORDED VOTE ON RESOLUTION 44/112:

In favour: Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Benin, Bhutan, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Byelorussia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Congo, Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Czechoslovakia, Democratic Kampuchea, Democratic Yemen, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, Ethiopia, Fiji, Finland, France, Gabon, Gambia, German Democratic Republic, Federal Republic of Germany, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kuwait, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libya, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, Spain, Sri Lanka, Sudan, Suriname, Swaziland, Sweden, Syria, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, USSR, United Arab Emirates, United Kingdom, United Republic of Tanzania, Uruguay, Vanuatu, Venezuela, Viet Nam, Yemen, Yugoslavia, Zaire, Zambia, Zimbabwe.

Against: United States.

Abstaining: None.

Absent: Belize, Comoros, El Salvador, Equatorial Guinea.

49/ A/43/506 and Corr.1 and Add.1 and 2.

Reproduced from Soviet-U.S. Relations: a briefing book, prepared by the Congressional Research Service. Washington, Congressional Research Service, 1990. p. 55-56. (CRS Report for Congress 90-182 F)

ANTI-BALLISTIC MISSILE SYSTEMS, ANTI-SATELLITE WEAPONS AND THE DEFENSE AND SPACE WEAPONS NEGOTIATIONS*

Key Facts. The United States and the Soviet Union are currently engaged in negotiations on defense and space weapons. The negotiations, a part of the Geneva-based Nuclear and Space Talks, address limitations on the research, development, testing and deployment of anti-ballistic missile systems (including the Strategic Defense Initiative, SDI), anti-satellite weapons (ASATS), and the future of the Anti-Ballistic Missile (ABM) Treaty. Both the United States and the Soviet Union have had anti-ballistic missile programs for over 30 years. In the 1972 ABM Treaty, the two countries agreed to limit the deployment as well as the development and testing of anti-ballistic missile systems.

As permitted by the ABM Treaty, both countries deployed one ABM system: the Soviet Union around Moscow; the United States at Grand Forks, ND. The United States deactivated its system shortly after it was completed in 1975. The Soviet Union kept its system, and according to the Department of Defense, began upgrading it in 1980. Also, as permitted by the ABM Treaty, both countries have continued research in all forms of ABM technology, including directed energy weapons and other advanced concepts.

In 1983, the Reagan Administration reconsidered U.S. strategy regarding ABM systems and sought research toward a transition from offensive to defensive strategic systems. With SDI, research on systems and components that would be capable of providing a comprehensive nationwide defense was greatly expanded. In 1987, the Reagan Administration also proposed demonstrating an initial strategic defense system that would involve deploying ABM components that are clearly in violation of the ABM Treaty. How far testing of the components for this system can proceed is a matter of debate.

The U.S. position at the Space and Defense Talks has been to replace the ABM Treaty with a separate agreement on Defense and Space that would permit widespread testing and deployment of ABM systems while offensive nuclear forces are being reduced under START. The Soviet Union has strongly opposed unrestricted development, testing and deployment of any ABM system beyond what they believe is permitted by the ABM Treaty. Until recently, the Soviet Union sought to negotiate a Defense and Space Protocol to START that could resolve U.S.-Soviet differences over the interpretation of the ABM Treaty and permitted SDI tests. The United States firmly resisted Soviet efforts to link START to an agreement on Space and Defense. The Soviet Union has since dropped this demand, although this does not mean the Soviets have accepted the U.S. notion of a transition away from offensive deterrence to defense or that testing ABM systems and components should be unconstrained. They also have stated that any violation of the current ABM Treaty through impermissible tests or deployments constitute grounds for withdrawal from a START agreement.

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* Prepared by Jack Moteff, Analyst in Advanced Technologies, Science Policy Research Division, March 1990.

In Geneva, the Soviet Union is likely to continue to press for assurances that the United States will adhere to the ABM Treaty and that any future deployment be subject to discussion. The Soviet Union may be willing to accept some testing of space-based ABM sensors and have proposed negotiating a list of acceptable testing parameters for ABM purposes. The United States continues to seek no constraints.

As with ABM systems, both countries also have pursued the development of ASAT weapons for many years. Since 1959, the United States has developed and tested air launched and ground launched ASATS and is currently developing both a ground launched kinetic energy ASAT and a ground-based directed energy ASAT weapon. Between 1968 and 1982, the Soviet Union tested a co-orbital ASAT weapon. The Soviets are thought to be developing other types of ASAT weapons too, including directed energy weapons. Soviet ABM missiles are also thought to have an ASAT capability. Whereas the United States does not have an operational ASAT weapon, the Department of Defense considers the Soviet co-orbital ASAT to be operational.

Limitations on ASATS are an agenda item in the Space and Defense negotiations. However, to date, efforts to establish a treaty controlling ASAT development and deployment have not been successful. The Carter Administration initiated efforts to negotiate a treaty with the Soviet Union banning ASAT weapons in 1978. Three rounds of talks were held between 1978 and 1979 without resolution. In 1981 and 1983, the Soviets introduced draft treaties at the United Nations to ban some ASAT devices. Also in 1983, the Soviets announced a unilateral moratorium on ASAT testing. The Soviets have now taken the public position that all ASAT weapons should be banned, and in 1987 proposed the creation of an International Inspectorate to inspect all satellites before they are launched to ensure that they are not ASATS or other space weapons. The current U.S. position is that there are too may ways to disable satellites and that verifying compliance with treaty restrictions would be impossible. Of particular concern are directed energy weapons whose firing would be difficult to detect and which can disable satellites.

Questions. 1. Would the Soviets be willing to allow more permissive research and testing of future ABM sensors and weapons? Under what conditions?

2. Under what conditions would the Soviets consider adopting a strategy that limits offensive nuclear weapons while deploying strategic defensive systems?

Summary

In late 1982 and early 1983, the Subcommittee on Arms Control, Oceans, International Operations, and Environment of the Senate Committee on Foreign Relations held hearings on space weapons and arms control. To explore these issues further in a discussion format not easily achieved in hearings, Sen. Larry Pressler, Chairman of the Subcommittee, asked OTA to conduct a workshop focusing on anti-satellite (ASAT) weapons as one aspect of space arms control. The workshop, held in Washington, D.C., on January 30 and 31, 1984, provided an opportunity for technical, diplomatic, military, and policy-analysis experts to interact, think out loud, and build upon each other's ideas.

The workshop was organized into six sessions, although issues involving anti-satellite weapons and arms control are not easily compartmentalized into distinct subject areas. Each session was introduced by a 10- or 15-minute informal oral presentation which set the stage for further discussion. This workshop proceedings volume is organized along the same divisions as the sessions, with some rearrangement.

The first session, an overview, reviewed technical aspects of anti-satellite systems and presented a candidate set of topics for discussion in later sessions. The second session covered pros and cons of ASAT arms control. Soviet attitudes and efforts regarding ASATs were the focus of the third session; U.S. attitudes and developments in ASATs and ASAT arms control were reviewed in the fourth. The effect of ASATs on the continued viability of the 1972 Anti-Ballistic Missile (ABM) Treaty, and vice versa, were covered in the fifth session. The last session centered on verification issues.

At Senator Pressler's request, OTA is publishing the workshop proceedings. OTA's agreement with the panelists was that the workshop report would discuss the viewpoints, ideas, and findings arrived at during the conference, but that particular statements or opinions would not be attributed to specific individuals. Therefore, the transcript has been paraphrased and rearranged to form this report. The proceedings have been circulated among the panelists, who were given the opportunity to suggest corrections and clarifications. They have not been reviewed by the Technology Assessment Board.

The workshop panelists were asked to raise and clarify issues, not to resolve them. No attempt was made to reach conclusions or develop consenses during the workshop sessions. However, OTA has noted and listed below several points where the panelists appeared to be in general agreement. These points are followed by a brief discussion of some of the fundamental bases for disagreement among the panelists. Following that is a list of some issues, raised during the course of the workshop, which were felt to merit further research and analysis.

POINTS OF GENERAL AGREEMENT

No arms control agreement can eliminate all anti-satellite capability. However, panelists differed in interpreting the significance of this residual ASAT capability which would be infeasible or impractical to ban. Some systems not designed to be ASATs (ICBMs, manned spacecraft, etc.) nevertheless have some ASAT potential, making some de facto residual ASAT capability inevitable. ASAT arms control supporters stressed that it would be minor compared to the capability of extensive ASAT or "space mine" efforts which could be undertaken in the absence of an arms control agreement, while some of the ASAT arms con-

Reproduced from Arms Control in Space: Workshop Proceedings. Washington, U.S. Congress. Office of Technology Assessment, 1984. p. 1-6, 9-23, 33-37, 49, 51-52.

trol opponents believed that the residual capability might nevertheless pose a significant threat to U.S. satellites.

ASAT arms control cannot eliminate the need to protect or supplement vital satellites with a variety of survivability measures. However, it can serve to lessen the measures required to protect space systems. Under any arms control accord, programs to ensure survivability of critical satellites or programs which supplement or replace their function will remain vital. The temptation to assume that survivability measures could be relaxed following an agreement must be resisted. "We could be that stupid," said one panelist, "but we don't really have to be."

The "verifiability" of an ASAT accord can only be assessed for a specified set of restrictions and measures, and any discussion of the verifiability of a particular provision ought to include consideration of the significance of potential violations of that provision. The panelists did not evaluate in detail, partly because of security classification restrictions, the verifiability of compliance with the various kinds of arms control agreements that were discussed. It was clear that the standards of verification required for effective ASAT arms control are highly controversial. Panelists agreed, however, that bans on testing would require less extensive verification measures than bans on possession, and that compliance with some ASAT arms control provisions could be verified with high confidence.

Future U.S. and U.S.S.R. activities in space hold great potential for generating uncertainty and misunderstanding regarding the countries' respective intentions. Workshop participants agreed that the Soviet Union will continue its vigorous exploitation of space, and that some Soviet activities will be perceived in the United States as provocative. Similarly, some American actions will appear provocative to the Soviets. Both countries will observe activities which they will not completely understand and which will cause considerable concern. Misunderstandings concerning the intent of various space actions could be particularly dangerous during crises or low-level conflicts.

Ambiguities might be lessened or resolved with some type of "rules of the road" or "behavior in space" agreement. Some panelists thought that an agreement concerning behavior in space, or towards space objects, might serve to reduce tensions and uncertainties. Such an agreement need not be associated with other measures limiting anti-satellite weapons systems; indeed, there might be value even if (thought some panelists) or especially if (thought others) there were no accompanying ASAT restrictions. Such an agreement might be modeled after the "rules of the road" on the high seas, which are embodied in several international agreements that recognize freedom to operate, lessen the risk of accidental collision, and minimize unnecessary provocation at sea. Possibly the most valuable feature of a "rules of the road in space" agreement would be the establishment of a forum like the U.S.-U.S.S.R. Standing Consultative Commission, which would help maintain an ongoing dialog between the United States and the Soviet Union and would permit discussion of activities whose significance was not clear. A "rules of the road" agreement should not be allowed to impede more serious provisions concerning space weapons if such provisions are found to be desirable. The precise form of a "space behavior" agreement was not explored in depth at the workshop, and the political and diplomatic procedures and tradeoffs required to negotiate and implement such an agreement were not addressed.

If ASAT threats are reduced by an agreement, there may be fewer reservations about placing important systems in space, creating in turn greater incentive for developing ASAT weapons. If an accord has the effect of relaxing survivability measures at the same time that reliance on space systems is increasing, then the growth of targets both valuable and vulnerable might provide strong motivation to attempt covert ASAT development. This possible paradox reinforced panelists' observations that an ASAT accord is no substitute for effective measures to reduce space system vulnerability.

Preservation of the functions now performed in space does not require the survival of all space

assets. Military support activities carried out in space are very important, but they can be duplicated or distributed among many space systems. Furthermore, many alternatives to space-based systems exist or can be developed.

The idea that the United States needs an ASAT weapon in order to deter enemy ASAT attack was not strongly supported. Many participants felt that the ability to retaliate against terrestrial assets served to deter ASAT attack at least as well as the ability to respond in kind against enemy satellites. Furthermore, one of the rationales other than deterrence which has been given for the U.S. ASAT program—to carry out attacks on particularly hostile Soviet satellites—conflicts with the ASAT's deterrent role. Nobody at the workshop felt that ASAT attack scenarios were well enough understood to predict the outcome of "tit-for-tat" ASAT retaliatory attacks in general. The likelihood and nature of subsequent escalation would be highly dependent on which satellites were attacked and under what circumstances.

The U.S. air-launched ASAT weapon now undergoing testing is clearly technically superior to the present generation of Soviet ground-launched ASATs. The ability to home in from a wide range of directions, and the flexibility of being launched from highly mobile aircraft, will make the U.S. ASAT a considerably more capable weapon if deployed. The United States will be able to launch consecutive ASATs much more rapidly than the Soviets, who are restricted in how rapidly their ASAT can be fired by their limited number of launch sites and by the time required to recycle them. There are also significant asymmetries in the target sets which are at risk to the two systems. Many important space functions are carried out by the United States using satellites in geosynchronous orbit, well out of range of the Soviet ASAT. Many Soviet satellites with similar functions use highly elliptical "Molniya" orbits, which could be vulnerable to U.S. attack at their lower altitudes. However, the United States would face severe logistical and operational difficulties in attempting to exploit this vulnerability. In addition, since Soviet satellites are shorter lived than U.S. satellites and are consequently replaced more frequently, the Soviets may be better prepared to reconstitute space systems than the United States would be.

In spite of asymmetries in capability, neither the existing Soviet ASAT nor the U.S. ASAT undergoing tests poses a severe military threat to the other side. The present level of ASAT technology is significantly limited. Both U.S. and U.S.S.R. weapons are restricted to targets in low Earth orbit and cannot reach geosynchronous orbit. Both systems may have to wait several hours for a target satellite to come within range of the appropriate F-15 base (for the U.S. system) or ground launch site (for the Soviets), although the mobility of the F-15 makes this restriction considerably less severe for the U.S. ASAT. If either the U.S. or the U.S.S.R. system were mated to boosters able to reach geosynchronous orbit, the ascent would take many hours. In light of these limitations, many treaty proponents would tolerate (although not necessarily prefer) a treaty which would "grandfather" existing systems. Perceptions differed as to the relative political implications of the existing U.S.S.R. system versus the U.S. ASAT which is undergoing testing, but nobody felt that the overall military balance was affected significantly by either—especially when compared with potential future ASAT developments.

A ban on testing ASAT weapons would greatly increase the difficulty of developing a high-confidence, high-quality, dedicated ASAT system. Panelists thought it would be very difficult to develop and field a highly capable new system with no detectable tests. Some tests might go undetected—for example, there are many perfectly legitimate activities involving rendezvous in space which could be made to be partial tests of ASAT interception capability—but many tests would be required to instill confidence in an ASAT system, and some of these would probably be detected. Banning the tests would force the violator either to forgo tests or to test covertly; covert testing, assuming that it could in fact be carried out undetected, would certainly be more difficult and less extensive than the overt testing that would be possible in the absence of a ban. In the absence of tests, all agreed that no one could be highly confident that a new system would be effective in difficult scenarios (against many targets in a short time interval and/or effective at geosynchronous altitude). If a system were to be developed without testing, the inability to make refinements based on tests and the lack of confidence developed through tests would degrade the system's military significance.

ASAT and ballistic missile defense (BMD) systems and technologies are closely related. As effective ASAT weapons are developed and introduced, boost-phase ballistic missile defense systems will become increasingly problematical since all such systems utilize space-based early warning systems and possibly other subsystems which would be vulnerable to ASAT attack. Many, although not all, prospective midcourse BMD systems would also have vulnerable space-based assets, and even terminal BMD systems would likely utilize space-based early-warning sensors. At the same time, even a poor quality or prototype midcourse or boost-phase BMD system may have very significant ASAT capability since satellites are much easier to destroy than missile warheads. Therefore, development of boost-phase and mid-course BMD systems will severely constrain ASAT arms control possibilities. Conversely, since ASAT and BMD technologies are related, treaties limiting ASAT development or testing will limit development and deployment of boost-phase and midcourse BMD systems. Of course, the 1972 ABM Treaty and 1974 protocol thereto already severely constrain testing, development, and deployment of BMD systems.

POINTS OF DISAGREEMENT

Disagreement over the desirability of an ASAT treaty hinges on basic philosophical differences over the role of arms control. Although acknowledged at the workshop, these differences were not discussed or debated significantly during the sessions. They are outlined below in an attempt to summarize some of the considerations most relevant to different sides of the ASAT arms control debate.

One attitude, supporting ASAT arms control, is that we value the safety of our own satellites more than we value the ability to destroy Soviet satellites. We want to protect those of our own military support functions which we presently carry out via satellites, and protecting them is much easier if our satellites are not threatened by a highly developed, highly capable Soviet ASAT. Preventing the Soviets from deploying an effective ASAT would be much more helpful than developing our own.

While a ban on all Soviet ASATs would be ideal, the principal U.S. interest is to prevent the Soviets from developing a highly capable system: one which works reliably, threatens satellites in geosynchronous orbit, operates with no warning, and/or attacks many targets at once. Several approaches, including banning ASAT testing, banning the development of new ASAT systems, or banning all dedicated ASAT systems, could inhibit such a Soviet development. Banning only tests or new developments would be more easily verified than banning all dedicated ASATs; however, a total ban might nevertheless be a more effective approach to preventing development of a highly capable Soviet system. Although no agreement can eliminate all ASAT capability, supporters of ASAT arms control felt that an agreement could be devised which would make Soviet development of such a highly capable ASAT system very difficult, and that such an agreement could be adequately verified. The criterion for supporting an agreement would be improvement in the security of our space systems as compared to not having an agreement.

A contrasting approach considers military competition between the United States and U.S.S.R. to be inevitable, with arms control in many cases not being an effective or appropriate alternative to that competition. Accordingly, the relevant measure of national security would be relative advantage or disadvantage of the United States with respect to the U.S.S.R. Those holding this view consider it essential to deny the enemy the use of space during a conflict when such use provides a military advantage. In the case of ASAT arms control, even if U.S. satellites were to be safer with an ASAT limitation or test ban than without one (which would almost certainly be the case), a treaty might not be appropriate if it would benefit the Soviet Union more than it would the United States. Such asymmetrical advantage might arise under an ASAT accord for two reasons: First, a treaty would divert the military competition away from an arena (ASAT competition) where the United States would otherwise have been able to exploit its superior ability to develop highly sophisticated technologies. Second, the Soviets might cheat. Because of the asymmetric nature of Soviet and American societies, it is argued, the Soviet Union is much more likely than the United States to cheat on an agreement. For the same reason, Soviet attempts to cheat are more likely to be successful. Whether or not the kinds of violations which might go undetected would in themselves pose major threats to U.S. security, any covert violation would work to our military disadvantage and would have undesirable political and psychological consequences as well.

There is disagreement regarding how much significance can be attributed to residual or covert ASAT capability. The panelists agreed that a considerable testing program is required in order to have high confidence in an ASAT system. However, there are differences of opinion regarding how significant an incompletely or covertly tested system might be. A covert system might not engender high confidence, it might not be as reliable as a dedicated, overtly tested system, and it might be discovered, but it might nevertheless still be developed. There is disagreement not only about how remote this possibility is, but also about how this possibility affects the relative advantages of a treaty versus the risks.

ASAT arms control is also complicated by more general considerations regarding the military use of space. On the one hand, emplacing weapons in space or using weapons against targets in space can be seen as breaking a de facto political taboo which would be difficult to restore. Furthermore, introducing weapons into space might make the world a more dangerous place; this is now almost universally believed to be the case concerning introduction of multiple independently targetable reentry vehicles (MIRVs). On the other hand, any space arms control might be viewed as a political and psychological barrier inhibiting the much wider exploration and exploitation of space as a theater of military operation. A primary example of the wider possibilities of space is ballistic missile defense—while many would not be willing to limit ASAT weapons at the price of impeding investigations into the possibilities of BMD, others see those restrictions on BMD which would be included in an ASAT accord as reinforcing the ABM treaty in support of its original and continuing goals.

TOPICS FOR FURTHER RESEARCH

Among the more general subject areas suggested to the workshop for further research were possibilities for "rules of the road" agreements in space. As noted above, many participants believed that some measures to reduce uncertainty and ambiguity in space might be desirable. Although possible models were proposed, potential agreements were not discussed in detail. What sort of mechanisms (be they unilateral actions, treaties, or informal working arrangements) could be established to permit mutual U.S. and U.S.S.R. use of space with a minimum of suspicion?

Are there ways of characterizing ASATs such that we can define and ban the most threatening or destabilizing types? Certain activities in space are clearly more threatening than others, just as certain activities are more visible than others. Is there a way that a "rules of the road" agreement could focus on the more dangerous rather than the more visible? What are the implications for verification and for stability?

No treaty of any kind can be perfectly verified. Several questions arise in handling ASAT treaty provisions which must therefore be verifiable only partially, or with less than 100 percent confidence. One problem involves how general or specific treaty provisions must be made. Treaty language intended to prevent some particularly threatening activity (e.g., testing ASAT interceptors at geosynchronous orbit) might be phrased in general terms (e.g., forbidding all ASAT tests) which would include less threatening activities that might be less verifiable (e.g., testing ASATs in low earth orbit where they might be masked as non-ASAT-related operations). What are the implications of having varying levels of confidence in verifying compliance with treaty provisions? Are activities which are not explicitly proscribed under a treaty necessarily condoned?

Another verification issue requiring further work involves cooperative verification procedures. Although existing rules regarding freedom of navigation and innocent passage on the high seas permit forces of one country to approach those of another, approaching a foreign satellite closely enough to examine it in space might nevertheless not be taken kindly in the absence of prior approval. If nuclear weapons are to be kept out of space with high confidence, then cooperative inspection procedures (either in space or on the ground) will likely be required. Can such procedures be arranged?

Overview

This workshop focused on anti-satellite weapons as an arena for arms control. Early in the first session, however, a panelist pointed out that such a focus in many ways creates an artificial distinction. Space holds a special "emotional allure." Much of the public debate concerning the militarization of space may result as much from that allure as from an informed judgement of the contribution of space activities to the military balance of power.

"Nuclear weapons and nuclear war remain the most important focus for arms control," a panelist pointed out. "ASAT arms control could reinforce nuclear arms control, but it could also divert attention from that central, overriding threat." At the same time, however, he and the remainder of the panel recognized that the appeal of space for military support operations is indeed high, and that the "allure of space" cannot be neglected in any discussion of ASAT arms control.

ORGANIZING DISCUSSION

Three ways of organizing discussion about ASATs were presented in the opening session. The first is to enumerate the various mechanisms of destroying satellites. There are essentially three distinct types: 1) direct interceptors, such as the current U.S. and Soviet ASAT weapons which home in on and then destroy target satellites; 2) "space mines," satellites which are stationed in orbit and later detonated to destroy nearby satellites; and 3) directed-energy weapons, which destroy satellites by delivering particle or radiation beams from a distance.

Other techniques such as concealment, spoofing, jamming, capturing control, and attacking ground stations, can disrupt the operation of a satellite. The difference between interfering with a satellite and permanently disabling it is significant, especially with respect to what is possible or desirable to regulate in a treaty. This distinction was made several times during the workshop.

A second method of organizing ASAT issues is to focus on the functions of potential target satellites and on the implications of subjecting these satellites to attack. So far, there are five primary roles for military support satellites—communications, surveillance and warning, navigation, meteorology, and geodetic survey. Different measures may be required to preserve each of these different functions in the presence of an ASAT threat.

A third organizational scheme is to enumerate anti-satellite attack scenarios and consider their effects on military capabilities and their prospects for escalation. Journal articles and press reports have discussed "just about every possible circumstance" involving anti-satellite activity, from tampering in peacetime to global nuclear war. Studying various possible scenarios has the advantage that, while ASAT technology can and will change, the scenarios for ASAT conflict may be more constant.

DISCUSSION FOCUSES

According to one panelist, the intersections or confluences of these three approaches—ASAT technologies, tempting or particularly threatening targets, and plausible circumstances—show the relevance of ASAT weapons and tactics to arms control. He singled out in the first workshop session several points about which further discussion could be focused. These issues, along with some items identified later in the workshop, are briefly described below and include:

RESIDUAL ASAT CAPABILITY

Many systems can destroy satellites besides those built or designed for that purpose. For example, ICBMs can be reprogrammed to attack satellites rather than terrestrial targets, giving both the U.S. and U.S.S.R. a de facto nuclear ASAT capability. The nuclear-armed Galosh anti-ballistic missile (ABM) interceptors, deployed by the Soviet Union around Moscow under the terms of the 1972 ABM Treaty, can easily destroy satellites passing overhead at altitudes lower than about 1,000 km. However, several panelists pointed out that the use of nuclear warheads against satellites is not plausible in situations short of nuclear war.

There is also nonnuclear residual capability. Rendezvous and docking procedures used in manned spaceflight could be applied to ASAT interception. With sufficient radar support, it is conceivable that Galosh interceptors having conventional warheads might be effective against satellites.

Since the above systems would remain even if all dedicated ASAT systems were banned, panelists agreed that residual ASAT capability will exist under any arms control regime. The more that space utilization and space technology develop, the greater the residual ASAT threat will become. Therefore, panelists strongly emphasized that no arms control agreement can replace the need to make the functions that we carry out in space survivable (see app. A). Functional survivability includes protection against non-ASAT threats, such as attacks on ground stations, and it does not require survival of all space assets. Space systems can be duplicated, and non-space-based alternatives for many support functions now done in space can be developed. Panelists noted that survivability would be easier to ensure if dedicated ASAT systems, especially highly threatening future ones, were controlled.

Determining the level and effectiveness of residual ASAT capability is important to weighing the desirability of any treaty. An ineffective ASAT which had no more capability than the residual capability of non-ASAT systems would not significantly increase the threat these non-ASAT systems potentially pose to satellites. There is, then, some minimum level of capability that an ASAT weapon would have to exceed before its existence would be significant. It would make little sense for an ASAT treaty to require a level of verification holding ASAT capability far below this minimum. However, exactly where this minimum level is located is a highly debatable point. Panelists who felt that the residual capability of non-ASAT systems was quite significant questioned the value of negotiating any limit to dedicated ASATs at all. The level of residual ASAT capability was discussed further in the verification session of the workshop.

COMPARISON OF U.S. AND U.S.S.R. ASAT WEAPONS

Although this topic is unavoidable in any discussion of ASATs, several panelists warned against overemphasizing the two countries' respective capabilities in isolation, without simultaneously considering their respective target sets and possible scenarios.

Both U.S. and U.S.S.R. weapons are designed to intercept target satellites using a three-step procedure. First, ground-based sensors identify the target satellite and determine its orbit. Next, the interceptor is launched and guided towards the intercept point, and finally, the interceptor's homing sensors are activated and it closes in on the target satellite. However, while the U.S. air-launched ASAT climbs directly towards its target satellite in ten or twenty minutes, the Soviet ground-launched ASAT must roughly match orbits with its target, a process which has taken up to several hours in tests.

The range of the booster and the homing process determine which target orbits an ASAT weapon can threaten. The U.S. Miniature Homing Vehicle (MHV) ASAT weapon now undergoing testing destroys its target by direct impact and can home in on its target from a wide range of directions. It needs only to get to the same place at the same time as its target, and does not need to match orbits with that target. The present generation of Soviet ASATs, on the other hand, is **co-orbital**—it needs to be in the same place at the same time traveling roughly in the same direction at the same speed as its target. So far, all Soviet ASAT tests have been conducted against targets in orbits with inclination angles near 65 degrees.

Workshop panelists felt it "beyond doubt" that the U.S. air-launched approach is "clearly superior" to the Soviet ground-launched technique. Besides the limitation of having to share its target's orbit, the Soviet ASAT is restricted by the small number of launch sites that can handle its modified SS-9 booster. As many as twelve hours might be required, while the Earth turns under the target orbit, to bring the target within range of a launch site. The Soviets are further limited by the recycle time of each launch pad, and they cannot launch many ASATs in rapid succession. U.S. air-launched ASAT interceptors can be launched much more rapidly, and from a much wider geographic area, than the Soviet ground-launched ASAT. The advantages of the U.S. ASAT's airplane-launched approach, and its direct homing interception, more than compensate for its altitude limit, which has not been released by the Air Force but was estimated by a panelist to be considerably lower than that of the Soviet ASAT. Although present U.S. plans call for ASAT-equipped F-15 squadrons having the associated logistical support to be based only at two sites within the continental United States, the planes and the associated support structure could be based in other areas to give even wider geographic coverage and more immediate response.

Another important asymmetry between near-term U.S. and U.S.S.R. ASAT capabilities is the target sets which each weapon will face. Many critical functions which the United States performs in space are carried out by satellites in geosynchronous orbit, far out of range of the Soviet ASAT. Similar functions for the U.S.S.R. are in many cases carried out by satellites in highly elliptical "Molniya" orbits, which could be vulnerable to U.S. attack at their lower altitudes. Present plans for deploying ASAT-equipped squadrons within the continental United States would not permit such attacks, but suitably equipped planes might be able to attack these Soviet satellites if they, and the appropriate logistical support, were based in the Southern Hemisphere. Even assuming appropriate bases could be obtained, in-flight refueling would be required.

Countering the potential advantages of the United States system is that it is still undergoing preliminary testing, whereas the Soviet ASAT has been tested, in a restricted manner, about twenty times over the last 16 years. The U.S. Department of Defense considers the Soviet ASAT to be operational. A panelist warned against comparing something that is "technologically possible that one side doesn't have" against an opposing system which "perhaps looks a little bit like a turkey" but in fact does have some capability. At any rate, no one doubted that the U.S. system could be made operational within a few years at most.

MILITARY ROLE IN SPACE

Much of the concern about ASATs and ASAT arms control deals with the role of satellites in military activities and the corresponding threat to military capability posed by ASAT weapons. Space systems are used extensively for military support, but satellites do not now fill a crucial, indispensable, and irreplaceable role. Many functions now carried out in space can be performed by other means. A paradox arises in that, to the extent that ASAT arms control masks the intrinsic vulnerability of satellites, alternatives to space systems may not seem necessary and satellites will be increasingly relied upon. If space utilization grows, so will the incentive to build

ASAT weapons. The solution is for arms control, if pursued, to supplement satellite survivability and redundancy programs and not to replace them. This point was repeated throughout the workshop: ASAT arms control cannot be a substitute for protecting and duplicating satellite functions.

ASAT ATTACK SCENARIOS AND POTENTIAL FOR ESCALATION

Does ASAT attack have a unique potential for triggering wider conflict? Does it imply that future conflict might be restricted to space? These points stimulated considerable discussion, but the panel doubted both.

Since military satellites are used principally for support activities, they don't functionally differ from terrestrial support systems. "Is the sinking of a U.S. intelligence ship not as likely and as inflammatory in a crisis as interception of a U.S. spy satellite?" questioned one panelist. Another panelist pointed out that "war in space cannot at all be separated from war on Earth." In any conflict, each side has certain objectives, and they are on the ground. "You don't shoot satellites just for the fun of it."

Other participants pointed out, though, that an ASAT attack might be less provocative than a terrestrial attack since people would not be directly threatened. "Maybe you destroy the 'allure of space'," said a panelist, "but you don't kill anybody." One panel member stressed that one cannot dismiss isolated ASAT scenarios to consider ASAT attack only in the context of a wider conflict. "I am skeptical about that because the United States has worked as hard as it possibly can to make itself extraordinarily vulnerable" to a low-level ASAT attack. "We have nothing in the pipeline to replace anything that's in space."

One panelist stated that the most worrisome ASAT scenarios involve low-level conflicts. In desperate cases, even a party not having a dedicated ASAT weapon might be tempted to attack an opposing satellite with whatever means could be arranged on the spur of the moment. In a low-level crisis which had not yet escalated to such a stage, however, existence or lack of a dedicated ASAT able to intercept with high confidence a threatening satellite might make the difference between attacking and not attacking. Carrying out such an attack "would be a tremendous temptation if it were easy to do so and could be done quickly and precisely and with very low collateral damage," even with the attendant risk of escalation.

Another panelist disagreed, maintaining that having fewer or poorer weapons does not necessarily lower the probability of their use. If a power feels that conditions warrant an attack on a satellite, it will be as likely to carry out that attack if it has one weapon as if it has 100. A decision of that magnitude will be a response to many internal and external pressures. "It isn't going to happen by itself," and if it is deemed to be necessary it may as likely happen with an improvised system as with a dedicated one.

An ASAT attack scenario which has been widely discussed involves attacks on the satellite-borne sensors that provide the U.S. early warning of a Soviet first strike. One participant minimized the importance or plausibility of such an attack scenario. A Soviet attack on warning sensors to prevent a preemptive or "launch-under-attack" U.S. strike might instead trigger that strike. So, if it were not to reveal an imminent Soviet nuclear attack, any Soviet ASAT attack would have to be nearly simultaneous with the launch of the ICBMs that it was intended to mask. Since any direct-intercept ASAT would take several hours to climb to the U.S. early warning sensors at geosynchronous altitude (no existing ASAT is presently capable of getting that far), only yet-to-be-developed directed-energy weapons or pre-emplaced space mines would present a significant threat in this scenario.

At any rate, the United States does not rely solely on early-warning satellites for notification of impending attack. Ground-based radars provide a backup, and for submarine-launched missiles they give negligibly less warning time than space-based sensors. Ground-based radars can also be supplemented by ship-borne, air-borne, and rocket-borne sensors.

CONNECTIONS BETWEEN ASAT AND BALLISTIC MISSILE DEFENSE

There are quite significant strategic and technological links between anti-satellite weapons and ballistic missile defense (BMD) systems. ASAT issues are central to BMD, and while consideration of BMD is less crucial to analysis of ASAT per se, the two subjects have significant overlap.

One connection is that any effective BMD (except for local, low-altitude site-defense systems) is an even more effective anti-satellite weapon. Even a poor BMD can have significant ASAT capability since satellites are much easier to destroy than missile reentry vehicles (RVs). A system used for ASAT would face at most a few dozen targets, and therefore could take much more time to attack a satellite than a system used for BMD could allocate to each of the up to 1,000 ICBMs or thousands of warheads in a massive attack. Satellites are intrinsically more vulnerable to damage than are RVs, and in a great many ASAT scenarios, attacks on satellites would take place in a much less hostile environment than the nuclear war in which a BMD would have to operate. Furthermore, an orbiting satellite's trajectory is completely predictable, except for limited maneuvers, making a satellite in effect a fixed target.

A second link between ASAT and BMD is that BMD systems (again with the possible exception of local site-defense systems) have space-based elements which would be vulnerable to ASAT attack. Even if a BMD system did not use weapons based in space, it would likely have space-based sensors and communications links; any BMD system intended to attack ICBMs during their boost phase necessarily would require space-based sensors to detect missile launch. If BMD weapons systems were put in orbit, they would be ideal targets for each other. They would be large, expensive, and hard to miss. All indications at present are that space-based weapons would be much cheaper to destroy than to replace "probably by a factor of 10. Right now it looks like a factor of 1,000." On the other hand, they might be capable of self-defense once they became operational.

As ASAT technology is perfected, it will become increasingly unrealistic to deploy "anything that's space-based and expensive." Conversely, if BMD technology is significantly developed, it will severely constrain the possibilities for ASAT arms control, but it might also elevate strongly the incentive for ASAT arms control.

PROSPECTS FOR VERIFICATION

The issue of verifying compliance with an ASAT accord occupied much of the later workshop sessions. Panelists agreed that a total ban on **anything** having any ASAT capability would be both infeasible and unrealistic considering that residual ASAT capability (ICBMs, manned spacecraft, etc.) will invariably remain even if all **dedicated** ASAT systems are banned. There was also considerable agreement, though, that the extensive testing program necessary to develop and acquire confidence in an advanced ASAT weapon would almost certainly be detectable, and that a ban on such testing would require less extensive verification measures than a ban on possession. These issues are discussed further elsewhere in this report (p. 39 ff.).

"RULES OF THE ROAD"

Another important point developed in later sessions was the concept of "Rules of the Road" or "Utilization of Space" agreements. Whether or not some agreement limiting ASAT weapons or testing is desired or implemented, panelists saw a use for an agreement between the United States and U.S.S.R. which would allow each party to continue its use of space without unnecessarily threatening the other. The United States and U.S.S.R. are each likely to conduct space activities which will appear provocative to the other, and some arrangements for reducing uncertainty might be helpful. The form of such an agreement was not discussed in detail; some additional discussion is reviewed in later sections of this report.

PRESENT TECHNOLOGY

The panel agreed that present ASAT technology (both Soviet and U.S.) is limited in significant ways, and that developing systems free of these limitations would require testing programs which would almost certainly be observable. Both existing systems (the Soviet system and the U.S. system undergoing tests) are only capable of reaching low earth orbit (on the order of 1,000 km)—neither can reach important satellites located at geosynchronous orbit (36,000 km). Both systems have inherent time delays, in waiting for targets to come within range of the launch site and in reaching their targets once launched. (The U.S. system, however, is significantly less constrained in these respects.) Both systems leave intact the adversary's ability to launch ASATs. There was general agreement that present ASAT weapons are much less threatening, and much less destabilizing, than what could be deployed in a new generation of ASATs, including ones which could attack many targets promptly and which could reach geosynchronous orbit.

As an example, one panelist posed the case of both the United States and U.S.S.R. having constellations of space-based beam weapons. As mentioned previously, such systems would likely be targeted at each other. Whichever side attacked first would not only retain its own ASAT (or BMD) capability but would eliminate its opponent's. This extreme incentive to attack first would be highly destabilizing.

Another participant took issue with this scenario, stating that the systems would likely operate so that such an attack by one side would result in most of both constellations being destroyed. For instance, one party detecting an attack could detonate space mines trailing its opponent's systems. All panelists agreed, however, that the present systems are not as threatening as future ones could be.

Descriptions, Pros, and Cons of Possible Agreements

FOCUSES AND PHILOSOPHIES

Before the United States undertakes to negotiate a treaty, it must determine that a treaty would be desirable. Could there be a treaty which would be in our interest, recognizing that Soviet interests do not coincide with our own? We then need to ask whether such a treaty might also be in the Soviet interest. If not, it is pointless to continue. It is not sufficient to find a single set of actors on each side that would be in favor of a treaty. In order to be acceptable, a treaty must be desirable to a large number of players on each side.

Early in the workshop, a panelist questioned whether anti-satellite weapons were indeed an appropriate focus for arms control. He pointed out that the technology and concepts are still being developed. Furthermore, given that some residual ASAT capability will always exist, one can't deny a country the ability to destroy satellites. Although an ASAT arms control accord might include some desirable features, the panelist felt that those goals might better be pursued in association with other arms control ventures.

Another panelist stated that an ASAT agreement would greatly increase the security of our satellites by limiting the development of new ASATs that could be considerably more sophisticated than the present systems. Such an agreement would make the task of protecting our satellites much easier. We must compare the residual ASAT capability under a treaty with the threat to our satellites in an all-out ASAT competition, he pointed out.

One panelist felt that we should be seeking a stable stopping point to the ASAT competition, or at least some intermediate points that would slow down the race, reduce tensions, and lend themselves to further negotiation. In particular, some concern was expressed about the U.S. ASAT being deployed without sufficient consideration of its long-term or possibly irreversible implications. An interim accord would provide some time.

Many participants supported the idea of finding ways to prevent "provocative and inflammatory" activities in space. Panelists realized that both the United States and the Soviet Union will continue to utilize space in ways which might have great potential for creating uncertainty and misunderstandings. This possibility could be mitigated by an arms control agreement. "Survivability is not the only goal" of a space arms control agreement, suggested a panelist, "and in my mind not even the main goal." He explained that the case for arms control really rests on the Soviets' desire to come to some working agreement with us so we both can develop space capabilities "without coming to clashes or crises or problems." This panelist supported a "rules of the road" agreement which would "provide some limit on activities which are going to pose major puzzles" to both the United States and the U.S.S.R. This form of agreement might or might not include an ASAT ban.

We and the Soviets tend to legislate the norms of international conduct by our actions and our agreements, noted a participant. In this manner, we have, for example, in effect declared that "offensive nuclear weapons are okay to have," but that "they're not okay to use directly in a threatening manner in crises." Regarding anti-satellite activity, we have so far "pretty much legislated that it's okay to live and let live in space."

"An ASAT treaty," he continued, "ought to reinforce that healthy kind of approach to space."

PHILOSOPHICAL DIFFERENCES

A point which was readily recognized at the workshop, but was not discussed or debated in depth, was that disagreement about the value of an ASAT accord stems from deeper philosophical differences about arms control in general.

Putting it a little simplistically, treaty proponents feel that our national security will be better with an ASAT treaty than without one, and that such a treaty can be verified well enough to ensure our security. Treaty opponents, on the other hand, focus on possible asymmetries in the relative costs and benefits of a treaty to the United States and to the Soviet Union. The Soviet Union, they feel, would benefit more from United States compliance than the United States would benefit from Soviet adherence with possible cheating. They feel that arms control is appropriate only if it would be advantageous to the U.S. in spite of this inherent asymmetry.

Is the criterion for negotiation that we end up better with a treaty than without one? Or, is it rather that our position with respect to the Soviets be better with a treaty than without one? Similarly, there are differences in overall attitudes concerning space and space arms control. Some view deployment of space-based or space-directed weapons as the breaking of a de facto political taboo, which would not only make the world more dangerous but would also be difficult to reverse. Alternatively, any space arms control treaty could be seen as a political and psychological barrier to the wider exploration and exploitation of space as a theater of military operation.

ASAT LIMITATION TREATIES

In discussing possible forms of ASAT arms control, the panel categorized five types of ASAT arms control agreements:

1. Bans on all testing, use, and possession of all ASAT capability.
2. Bans on all testing, use, and possession of dedicated ASATs.
3. Bans on use and testing, but not possession, of dedicated ASATs.
4. Bans on development or use of new types of ASATs; no restrictions on existing ASAT systems.
5. Bans on use of ASATs; no restrictions on possession or testing.

Panelists readily agreed that the first type of agreement is unattainable. Some non-ASAT systems have some capability to serve as ASATs, so residual capability would remain even if dedicated ASAT systems were banned. Recognizing this fact, the second type of agreement would deal only with dedicated, and presumably more threatening, ASAT systems.

Most of the workshop discussion about ASAT limitations involved a testing ban which might or might not include existing systems and which might or might not prohibit ASAT possession. Testing of a dedicated ASAT weapon would be more visible, and less ambiguous, than its possession. To avoid some of the difficulties of a more extensive ban, a treaty could permit possession of ASATs but ban use and testing. Without testing, the significance of possible ASAT possession might decrease with time. In the view of some, new systems could not be relied upon, and confidence in existing systems would slowly degrade.

The fourth type of agreement, conceding the existence and operation of existing systems, would still restrict the deployment of new and more threatening ASATs. It would also suppress the question of residual ASAT capability, since if both sides had a dedicated system it is unlikely that either would use "baling-wire" systems. Considering the disparity between the U.S. and the Soviet ASATs, though, several panelists felt that the Soviets might not be willing to concede to the United States the right to test and deploy the air-launched MHV ASAT without reserving the right to develop a system at least as effective.

The fifth type of agreement in the above list would prohibit the use of ASAT weapons and might also delineate acceptable behavior by codifying some set of "rules of the road." Such measures attracted much interest among the panelists as supplements to, as well as alternatives to, ASAT limitations. Proposed agreements of this sort are not as well defined as prohibitions of ASAT testing or possession, for which draft treaties have been prepared by various parties.

ASAT ARMS CONTROL: PRO ARGUMENTS

ASAT treaty proponents see an ASAT arms race as not serving our best interests. "The burden is always on arms control to explain how the world is going to be better with the treaty than without," remarked a panelist, "and the burden is never on the person who just wants to keep blundering ahead to explain how the world is going to be safer that way." Treaty proponents see continued ASAT competition as unwise, and believe that a treaty would be worthwhile even if it served only to constrain future developments. Observing that the ASAT problem will not disappear completely, with or without a treaty, one panelist noted that "in the absence of restrictions, the problem is going to get a great deal worse."

Offense Dominance.—An ASAT race is not desirable because, for the foreseeable future, the offense will always win. Satellites are expensive, and they are inherently vulnerable because of their known trajectories, their limited numbers, and their fragility. Significant cost and performance tradeoffs are required to protect satellites against attack. Therefore, U.S. satellites are likely to be much cheaper to destroy than to replace. This balance will not be changed by deployment of a U.S. ASAT weapon, even if it is superior to the Soviet ASAT. Assuming that we need our own satellites much more than we need to attack Soviet satellites, treaty proponents believe that we should attempt to negotiate a mutual limitation on ASATs.

Defense and Possible Future Developments.—Arms control proponents particularly saw great value in ending the ASAT competition as soon as possible. Current technologies are relatively primitive compared to future possibilities, which could be very threatening. It is easier to protect satellites against the current threat than against subsequent generations of ASATs. The later that action is taken, the more systems will be deployed, the more complicated the technology will become, and the more difficult compliance with any treaty will be to verify. Adequately verifiable testing bans are possible, proponents feel, and they would severely limit the development of truly threatening anti-satellite weapons. The ASAT competition has not progressed so far that stopping now would be irrelevant.

We are now at a stage in which only our low-altitude satellites might be vulnerable, and we face the quite possible future alternative of having our entire in-orbit force structure subject to prompt destruction. Directed-energy ASAT weapons, for example, will very likely be deployed if there is no ASAT accord. Such weapons, having long ranges and near-instantaneous reaction times, would be destabilizing—especially if based in space. If such systems were developed by either or both sides, they would be tempting targets, and each side would have great incentive to attack first in order to disarm its opponent. In the absence of an ASAT accord, we are also likely to see the advent of space mines, which could be comparatively inexpensive. If space mines were widely deployed, most or all of our important satellites would be subject to almost instantaneous destruction.

Existing Unreliability.—Future ASATs will likely be much more reliable than the present systems, which has significant implications for stability. Neither the existing Soviet ASAT nor the U.S. ASAT under development can presently be considered highly reliable. The

U.S. weapon has never been tested against a target in space. According to published reports, the Soviet weapon has not functioned properly in a significant percentage of its tests. Some panelists did note, however, that without knowing the nature of and responses to these failures, we can not necessarily infer a reduced confidence or lower reliability of the Soviet ASAT.

Highly reliable ASATs, if they existed, might increase the risk that low-level crises would escalate. As discussed in the overview, confidence in the ability to attack a threatening satellite easily, quickly, and precisely may increase the likelihood of doing so. In a tense situation, posited one panelist, the United States or the U.S.S.R. might initiate ASAT conflict by reasoning "we're not going to kill anybody; we're not going to threaten anybody's strategic warning system, but nobody's going to take pictures of us for a few weeks now." Both the temptation and the danger of an ASAT attack against a reconnaissance satellite in a crisis would be "extraordinarily high."

Economic Pressure.—A panelist noted that ASAT limitations could forestall utilization of ASAT competition by the Soviets as a relatively low-cost means of applying pressure to the United States. Perceiving a full-scale military buildup by the United States, but constrained by the performance of their own economy, the Soviet political leadership may seek ways to pressure the United States without having to engage in an across-the-board response. In most cases, the development, or improvement, of an ASAT system is much cheaper than protecting against ASATs by duplicating or supplementing space assets.

Mutual Benefit to Treaty.—ASAT arms control advocates noted that ASAT arms control negotiations are not a "zero-sum" game. Both the United States and the Soviets would benefit from an ASAT accord. Soviet interest in negotiations does not mean that we must a priori oppose them. "Certainly you can't expect the Soviet Union to sign any agreement which works to their net disadvantage," explained a panelist, "but most people regard the elimination of nuclear war, or even the significant delay, decade by decade, of all-out nuclear war, as being to the advantage of the Soviet Union as well as the United States."

Private Sector Concerns.—One argument which has been made in favor of ASAT arms control found no support at the workshop. In the past, it had been argued that without an ASAT accord, private industry would be reluctant to invest in space systems which are inherently vulnerable to ASAT attack. Panelists pointed out that the Soviet's current capability to destroy anything in the United States or at sea has not affected the private sector. They noted, as an example, that the Soviet ability to shoot down airliners "which has been demonstrated" has not affected airline investment decisions.

A concern of private industry which was backed up at the workshop is the problem of space debris from ASAT weapons test. Studies mentioned at the workshop indicate that a significant source of debris in low-altitude orbit is Soviet ASAT testing and ASAT-related activity. ASAT tests at or near geosynchronous orbit would be of considerable concern to communications satellite companies.

ASAT ARMS CONTROL: CON ARGUMENTS

Much opposition to ASAT treaty efforts stems not from the desire to have ASAT weapons but rather from the viewpoint that arms control is not an effective or appropriate means of addressing the ASAT question.

Residual ASAT.—ASAT treaty opponents raised the problem of residual ASAT capability—means for destroying satellites which would be infeasible or unrealistic to eliminate by any form of agreement. They also noted that methods for interfering with the operation of systems using satellites, short of destroying them (jamming, spoofing, or attacking ground stations or support facilities), might be difficult to address in an ASAT arms control accord.

Asymmetric Societies.—The asymmetrical nature of the Soviet and the U.S. societies, according to arms control opponents, implies that there will be asymmetric advantage from any symmetric treaty. The Soviets are much more likely than the United States to cheat on an agreement, and if they do cheat they are much more likely to get away with it. Furthermore, there seem to be differences between the United States and the Soviet Union in interpretation of "borderline" activities—"I think we have learned over the last twenty years that the way the Soviet Union keeps a treaty is not exactly the way two-thirds of the Senate had in mind," summed up one participant.

Verification.—Treaty opponents are very concerned about the verifiability of compliance with an ASAT accord. No treaty, of course, is perfectly verifiable, but different people assess differently the likelihood (or significance) of activities which may escape detection. Inventories of ASAT interceptors on the ground or the contents of satellites in space may be difficult to monitor. Compliance with bans on ASAT interceptor testing may be difficult to verify since there are many legitimate activities requiring rendezvous in space which could be made to be partial tests of ASAT interception capability. Furthermore, even a small amount of Soviet cheating in an ASAT arms control agreement could be significant since U.S. satellites are long-lived, valuable, and limited in number. We would be more sensitive to loss of a few satellites than the Soviets, whose satellites have shorter lifetimes and are consequently replaced more frequently.

Limits on U.S. Strengths.—More general objections to ASAT arms control result from the constraints it would put on the ability of the United States to exploit its technological expertise. By permitting the Soviets to "make up lost time" in developing advanced ASAT technology, said a panelist, ASAT arms control would "allow the Soviets a major competitive advantage."

Both the United States and the Soviet Union have too great an interest in the military use of space to agree to an ASAT treaty that would deny the ability to engage in conflict there, he explained. "If there is conflict, there is going to be conflict in and from space. It's inevitable because of what we've been doing for about the last twenty years" by putting very valuable systems in space and using them to the extent that we do.

Ballistic Missile Defense. Another very significant source of opposition to ASAT arms control is the desire to investigate advanced ballistic missile defense technologies. Some of the concepts most attractive to BMD supporters involve "boost-phase" defenses which attack missiles as they climb out of the atmosphere. However, since effective boost-phase weapons would likely also be effective against satellites, they would almost certainly have to be restricted under an ASAT accord which limited the most threatening ASAT technologies. Systems capable of doing boost-phase BMD would be inconsistent with the existing 1972 ABM treaty, but supporters of BMD research may not wish to contend with a restrictive ASAT accord as well. An opinion expressed at the workshop was that "the ABM treaty is bad enough to have as a complicating factor in any type of transition towards strategic defense without adding a layer of porous ASAT agreement."

Difficulty.—A more pragmatic reason for opposing ASAT arms control is that the process of negotiating such a treaty with the involved executive agencies, with the Soviets, and with the Congress is "incredibly painful" and not worth undertaking in the absence of an overwhelming conviction that it would be in the national interest.

ASAT WEAPON: PRO ARGUMENTS

Those opposing an ASAT treaty believe that ASAT arms control is not in the national interest. They may also believe that having an ASAT weapon is in the national interest. Anti-ASAT treaty arguments and pro-ASAT weapon arguments, although related, are distinct.

Three justifications for developing anti-satellite weapons were reviewed at the workshop. Of the three, one was mentioned but not discussed in detail, and another was not supported by ASAT proponents on the panel.

Attack Hostile Satellites.—The primary reason for developing an American ASAT weapon is to deny the use of space to an adversary during conflict. The particular example cited by administration officials and by workshop participants is the threat posed by Soviet ocean reconnaissance satellites which are said to be able to locate U.S. Navy ships on the high seas. Those holding this view do not wish to allow the Soviets freedom to conduct reconnaissance activities from space which threaten American forces. They also expect that the Soviets will utilize other space assets for improving the effectiveness of their military forces ("force-multiplication") and want to be able to deny the Soviets these capabilities as well.

An American ASAT weapon could be stabilizing, it was argued, if used against Soviet reconnaissance satellites which would otherwise be available for retargeting Soviet missiles. In a "shoot-look-shoot" scenario, Soviet reconnaissance satellites would be used to locate U.S. military targets that had survived a first strike. This data would be used to retarget a Soviet reserve force to destroy those remaining targets. The Soviets likely know that they would probably need "more than one echelon of strategic attack" to carry out an effective strike against the United States homeland, argued a panelist. Denying them this "shoot-look-shoot" capability would make it harder to conduct an effective first strike, lessening its probability and therefore increasing stability.

Support Negotiations.—A second reason mentioned at the workshop for developing a U.S. ASAT weapon would be use as a "bargaining chip" to induce the Soviets to negotiate an ASAT treaty. Whether or not this viewpoint may motivate development of some weapons systems, it does not properly belong in a tabulation of "pro-weapon" arguments. If one seeks to negotiate a ban on ASAT weapons, for example, then one presumably has already determined that having an ASAT weapon is not necessary.

Deterrence.—The third reason given for having an ASAT weapon is to deter ASAT attack. This rationale was not supported at the workshop. Arms control supporters and opponents both felt that the ability to retaliate against terrestrial targets served to deter ASAT attack at least as well as the ability to retaliate against satellites. Satellites can be protected against ASAT attack in a number of ways, and having the capability to respond in kind was not thought to be singularly effective in protecting satellites.

A panelist also pointed out that the deterrent role of an ASAT is in opposition with, not in support of, the role of eliminating hostile satellites. If an ASAT capability is required in order to support objectives (such as preventing detection of naval surface units by Soviet satellites) which are unrelated to retaliation, then the deterrent value of an ASAT must be balanced against its potential use in initiating space conflict to attack hostile satellites.

"RULES OF THE ROAD"

Many panelists, including supporters of ASAT limitations as well as those questioning the effectiveness or utility of ASAT bans, agreed that some sort of international agreement concerning "rules of the road in space" could be beneficial. These rules could also include rules on space-related ground activities. While the nature of such an agreement was left vague, and the negotiation process which might conclude in such an agreement was not analyzed, several motivations and possible examples for such an agreement were raised.

Rules of the road would try to alleviate situations which either side would consider particularly dangerous. For example, they might inhibit effective placement of space mines by establishing a minimum separation between satellites. As both sides continue their operations in space, such rules may become increasingly valuable.

One of the functions of a regime of rules in space would be to reduce instances where seemingly dangerous activities are observed without the means of finding out exactly what is going on. Certain activities which might be provocative could be prohibited, or they might be required to be accompanied by an explanation, perhaps in advance, which had some basis for being believable. The most important function of such an agreement, suggested one panelist, might be the establishment of a forum where questionable activities could be discussed. That the forum would help maintain an ongoing dialogue between the United States and the U.S.S.R. would be healthy in and of itself. Alternatively, said another panelist, it would be nice to know that if the Soviets do something that we find very threatening, they did it on purpose. "We might still find ourselves getting dangerously close to a war, but at least we would know better where we stood." A panelist also pointed out that besides defining acceptable conduct, "rules of the road" might also give some basis for responding to certain violations.

A precedent for "rules of the road" is the ban in the 1972 ABM Treaty prohibiting interference with the national technical means used by each side to verify compliance with that treaty. This measure is a "function ban": it does not refer to satellites or space in particular, but rather prohibits interfering with the function of verification. Such a function ban might be extended by building upon the example of the 1971 "Agreement on Measures to Reduce the Risk of Outbreak of Nuclear War," which requires the United States and the U.S.S.R. to notify each other "in the event of signs of interference with [early warning systems] or with related communications facilities, if such occurrences could create a risk of outbreak of nuclear war." This clause could be strengthened to prohibit interference with the function of early warning in general without reference to satellites or ASATs. A very important motivation for rules of the road would be the recognition, such as that implicit in the 1971 Measures Agreement, that accidents will happen.

An additional model could be the international regime existing on the high seas, in which certain particularly hostile and dangerous activities have been banned. Similar bans could be applied to space activities. However, since the "rules of the road" on the high seas as they currently exist do not keep ships out of lethal range of each other, similar rules would not be sufficient to ban space mines. New measures would be required if it were desired to eliminate the threat of space mines by keeping satellites apart by more than a lethal distance.

"Rules of the road will not prevent ASAT attacks," pointed out one panelist. "Perhaps they can't even be verified very well. . . . Nevertheless, an agreement along those lines might be worth having precisely because it would reduce ambiguous acts" and minimize the chances of escalation or misunderstanding in a crisis. Panelists agreed that "rules of the road" would not require an ASAT ban; some of those supporting an ASAT accord felt that it would be strengthened by rules of the road; those opposed to an ASAT agreement saw merit in rules of the road as an alternative.

All panelists agreed that the Soviets are increasing their utilization of space, including their development of ASAT capability. That fact, taken with their willingness to negotiate space arms control with the United States, can be seen as indicating that they would like to jointly draw up some general rules of behavior. "If that's the signal, that's a very interesting signal," interpreted a panelist. "It makes it that much more useful to look for ASAT treaties that simply have the merit of putting some kind of terms of agreement on record, if nothing more."

GENERAL DISCUSSION

There was no agreement on how much the ASAT threat would be reduced by a treaty, or on the significance and likelihood of residual or covert ASAT activity. An important point is the extent to which residual, possibly covert, ASAT systems would place our spacecraft at risk under a treaty regime. "Is it going to be closer to one-eighth of the original threat or is it going to be closer to seven-eighths?" asked one participant.

GRANDFATHERING EXISTING SYSTEMS

The discussion of possible ASAT limitations, their advantages, and their disadvantages touched on a number of issues. One of these was the question of "grandfathering" existing ASAT systems: Should the Soviets be permitted to keep their system? Should the United States be permitted to continue developing its own? One panelist felt strongly that the objective of a treaty is to prevent the development of technologies and capabilities which are much more threatening than those existing now. Such a treaty would block the "sustained, organizational effort" required to implement such advances in ASAT technology. Existing systems, which are not nearly as threatening as future ones could be, might be grandfathered in such a treaty. Alternatively, further testing and development of existing systems could be banned, especially at higher orbits.

One panelist felt that the Soviets would not accept an agreement which would permit existing systems because of the asymmetries in capability between the U.S. and U.S.S.R. ASATs. The U.S. F-15 system, a far more capable weapon, will be able to destroy Soviet satellites much more rapidly than they could be replaced and would be sufficient to deny the Soviets access to low earth orbit for a considerable period of time. Given the Soviets' present technique for attaining higher orbits by using lower altitude parking orbits, the U.S. ASAT could effectively deny the Soviets the ability to reconstitute higher orbit systems as well.

Another panelist was skeptical about negotiating away the Soviet ASAT because of the measures that would be required to give the United States assurance that it had been dismantled. The Soviets have "only in a sort of Aesopian way" admitted that the present SS-9 based ASAT exists at all, he said, "which is not a hopeful way to start out on the negotiation" concerning the "extraordinary measures" required to ensure that the system had been dismantled. However, if the Soviet ASAT is neither eliminated nor balanced with a symmetrical U.S. capability, then the political viability of any ASAT accord in this country would be "very, very low."

U.S. ASAT REQUIREMENT

Another issue stimulating considerable discussion was the need for a U.S. ASAT weapon. There was widespread disagreement about the requirement for an American ASAT to deny the Soviets the ability to target the U.S. fleet with their ocean reconnaissance satellites. There were no panelists with Navy backgrounds ("we've been sinking the Navy without its representation," noted a participant), but at any rate there was little support for the position that the Radar Ocean Reconnaissance Satellite (RORSAT) is an extremely threatening system. The capability to destroy Soviet reconnaissance satellites is neither necessary nor sufficient to protect the U.S. fleet, it was pointed out. The United States has many ways to deny the Soviets intelligence from these satellites—RORSATs are vulnerable to a variety of electronic countermeasures. Studies made more than 10 years ago laid out a "long laundry list of things that could be done other than blowing it up," such as decoying and jamming.

Furthermore, there are many ways the Soviets can locate American ships without the use of RORSATs. "For instance, they can ask their own ships, which accompany our aircraft carriers," pointed out a panelist. "If they didn't have radar ocean reconnaissance satellites, they would have other things."

Also disputed was the argument that a U.S. ASAT would be stabilizing since it would deny the Soviets the ability to execute a "shoot-look-shoot" attack. That rationale is an example of the "impractical war conduct scenarios" which one can set up and then show to be impossible if only some particular weapon is built, a panelist said. "That is not a valid reason to oppose ASAT treaties."

Finally, the argument that a U.S. ASAT weapon is needed to induce the Soviets to negotiate was also challenged. "It is not supported by historical experience," said a panelist. "In 1978 and '79, the negotiations [with the Soviets on anti-satellite weapons] were very active and were moving along nicely, and we didn't even have a paper program—much less a system." He pointed out that the Soviets "accepted it on faith" that the United States was quite capable, technologically and industrially, of putting together a system if it wanted to. "If both parties feel they can't negotiate except from a position of strength, the conclusion is there will be no negotiations."

LIMITATIONS OF ASAT ACCORDS ON BMD DEVELOPMENT

According to some panelists, the effects of an ASAT accord on the future development of ballistic missile defense are some of the most important anti-treaty arguments. "They involve important issues of judgement." While it was in effect, an ASAT accord would prevent development and deployment of space-based ballistic missile defense, said an accord supporter. However, any such treaty could have provision for periodic review. Treaties can be mutually eliminated or unilaterally abrogated; they contain "all kinds of possibilities for not constraining ourselves for the indefinite future." However, another panelist countered that treaties "tend to become sacrosanct." Any attempt to withdraw from an ASAT accord would become a "major political football" which might obscure strategic considerations.

URGENCY

One of the most important points raised by treaty supporters was that, if an agreement is to be reached at all, there is great value in reaching it sooner rather than later. A treaty may be much harder to negotiate, and be much less effective, if it is delayed. In particular, many treaty proponents thought it would be "extremely damaging" to complete tests of the U.S. air-launched ASAT because the Soviets will react to that development. If, following future American tests, the Soviets believe the U.S. system to operate reliably, they may not be willing to concede the United States' right to keep that system without demanding that they themselves be permitted to match or exceed that system's capabilities. "Quit while you're behind," urged a panelist, "or while you're nominally behind." In another panelist's words, "negotiating from strength is a sinusoidal function and you have to pick your timing right. . . . We should be negotiating now because we are behind by just the right amount."

In arguing for an agreement as soon as possible, one panelist noted that the negotiations need not take a long time. "You do not have to negotiate the ultimate ASAT agreement, and the best agreement to negotiate first is the broadest one." Another panelist countered that while an agreement need not take a long time, it probably will take a long time for reasons which are more political than technical. "If you don't want an agreement and you don't go to the table, it is likely to take a very long time" to negotiate and conclude a treaty.

ASAT, BMD, and the 1972 ABM Treaty

ASAT systems and anti-ballistic missile systems are closely related, as are ASAT and ABM arms control. The development of ASATs can affect the continued viability of the existing ABM arms control regime; conversely, development of strategic defensive systems can affect possibilities for ASAT arms control. This section reviews the 1972 ABM treaty ("I have a rule . . . never to be flabbergasted at the same thing more than three times," explained a panelist, "but I am always somewhat surprised at how people forget what it is that the treaty says and what it does not say"). This section also discusses some of the relationships between ASAT and ABM, regarding both weapons systems and arms control measures.

REVIEW OF 1972 ABM TREATY

PURPOSE

The Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems, which entered into force on October 3, 1972, states its overall purpose in Article I:

> 1) Each party undertakes to limit anti-ballistic missile (ABM) systems and to adopt other measures in accordance with the provisions of this Treaty.
>
> 2) Each party undertakes not to deploy ABM systems for a defense of the territory of its country and not to provide a base for such a defense, and not to deploy ABM systems for defense of an individual region except as provided for in Article III of this Treaty.

This explicit declaration of purpose is an important aspect of the treaty. As time, technology, and circumstances change, it is possible to refer again to the declared purpose in order to develop specific new understandings which are required to modernize the treaty.

DEFINITIONS

An anti-ballistic missile system is defined, for the purposes of the treaty, as "a system to counter strategic ballistic missiles or their elements in flight trajectory." This phrase is followed by the words "currently consisting of" and then a list of three items: ABM interceptor missiles, ABM launchers, and ABM radars. The treaty is **not** restricted to those systems. It says what the current systems are, but it is intended to cover **all** ABM systems.

Note that the definition refers to **strategic** weapons. Systems to counter **tactical** missiles are not covered at all—"a loophole that we designed carefully, and which they are pushing through," according to a panelist (see app. B). Note also that the treaty defines an ABM as a system **to counter** strategic weapons. It does not say "system designed to counter," as the Soviets would have liked, nor does it read "system capable of countering," which was the United States' preferred wording. The United States was concerned that, by upgrading surface-to-air missiles (SAMs), the U.S.S.R. would be able to deploy a considerable ABM capability. The Soviet Union, on the other hand, was concerned that it would be forced to classify some 10,000 SAMs as ABM interceptors. The analogy of upgrading ASAT weapons to give them ABM capability is similarly relevant and similarly covered by the treaty.

This definition is essentially a capability test. All systems which are ABM-capable, whether or not they were designed for that purpose, are either considered ABM systems under the treaty or else are in violation of Article VI(a), which prohibits giving ABM capability to non-ABM systems. This article was "really aimed at SAM systems," explained a panelist, "but the same thing applies to ASAT systems." If an ASAT weapon is given the ability to counter strategic ballistic missiles, then "it's a violation or else it's got to count as an ABM system, one way or the other."

MAJOR PROVISIONS

The ABM treaty prohibits all ABM deployments which are not explicitly permitted. Article III bans all deployments other than two sites (amended by a 1974 protocol to one) on each side, each having restricted numbers of interceptors, launchers, and radars. These prohibitions, interpreted a panelist, are clear: "Can you deploy lasers? No. Can you deploy particle beams? No. Can you deploy squizzle dumps or freeble dobbles? No."

Article IV permits testing, at designated test sites, of certain systems not deployable under Article III. However, systems permitted at test sites or deployments are severely constrained by Article V, in which "each party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based." Only fixed, land-based systems can be tested, and only specified fixed, land-based systems can be deployed. "Development," as referred to in this provision, was defined in a statement to Congress by the chief U.S. negotiator of the ABM treaty: "It is understood by both sides that the prohibition on development applies to activities involved after a component moves from the laboratory development testing stage to the field testing stage, wherever performed." Interpreted by a workshop panelist, "if I see one outside the laboratory—a prototype, a bread-board model—if I see one, it's a violation. I don't have to see it tested." The second part of Article V prohibits a launcher from being able to fire more than one interceptor or be reloaded rapidly.

Upgrades are prohibited in Article VI(a), as discussed above. No non-ABM systems shall be given ABM capability or be tested in an ABM mode. The second part (b) of Article VI restricts ABM battle management radars by requiring early warning radars to be on the periphery of the country and oriented outwards. Agreed Statement F, approved by U.S. and U.S.S.R. delegation heads at the same time that the treaty was signed, excludes radars used "for the purposes of tracking objects in outer space or for use as national technical means of verification" from the location and orientation restrictions in Article VI(b).

Article XII prohibits interference with verification of the treaty, both by banning interference with the national technical means used for verification and by prohibiting "deliberate concealment measures" which would impede verification by national technical means. Article XIII establishes the Standing Consultative Commission to handle questions relating to treaty compliance, to consider possible amendments, and to consider proposals for further limiting strategic arms.

Agreed Statement D of the ABM treaty discusses components based on "other physical principles" and capable of substituting for interceptors, launchers, or radars. Capability, again, is crucial. If a new device can substitute for a launcher, interceptor, or radar, its deployment is prohibited. If it is instead only an adjunct or supplement, it would be permitted. This article specifies that "specific limitations" on such new systems and their components would be "subject to discussion" in the Standing Consultative Commission, and that such discussion might lead to amendment of the treaty. Only if the treaty were amended to permit these new components would their deployment be allowed; otherwise, they are prohibited.

CONNECTIONS BETWEEN ASAT, BMD, AND THE ABM TREATY

As mentioned above, developing an ASAT system which had BMD capability, or upgrading one to give it BMD capability, would be a violation of the ABM treaty. The test of violation is capability—can the ASAT destroy missiles? There is an absolute prohibition on anything not fixed on land at an ABM site or a designated test site which is able to destroy "strategic ballistic missiles or their elements in flight trajectory."

National technical means of verification are protected from interference in Article XII. Reconnaissance satellites are not explicitly mentioned in the treaty text, but they are listed as an example of national technical means in the transmittal letter from the Secretary of State to the President which accompanied the treaty and were also mentioned in the transmittal letter to Congress. ASAT attacks against reconnaissance satellites used to monitor compliance with the ABM treaty are, therefore, banned by that treaty.

Another relevant connection between ASAT systems and the ABM treaty involves the radars required for ASAT battle management (in the absence of an ASAT treaty) or ASAT treaty verification (if such a treaty is concluded). These space-track radars will physically be very hard to distinguish from early-warning radars and ABM battle management radars which are covered by the ABM treaty, and any ASAT treaty may need specifically to address space-track radars to ensure that the prohibitions against ABM battle management radars are not circumvented. However, according to a panelist, the signal emitted by a radar "would be quite different if it were fundamentally a space track system than if it were an ABM," making somewhat easier the task of distinguishing between the two (see app. B).

TECHNOLOGIES

There is great overlap between BMD and ASAT technologies. In general, even a poor or prototype anti-ballistic missile could be an excellent ASAT. Looking at BMD systems designed to attack a ballistic missile at different stages in its flight trajectory, we have three categories of BMD systems:

1. **Boost-phase BMD.**—BMD systems designed to attack missiles as they are climbing out of the atmosphere under powered flight have great ASAT potential. Therefore, any treaty effectively limiting systems having ASAT capability would almost certainly have to restrict boost-phase BMD. Of course, the ABM treaty already in effect prohibits boost-phase BMD: in order to respond quickly enough to attack missiles in their boost phase, a boost-phase BMD system will either require space-basing of weapons components or else it will need to launch "pop-up" components immediately upon detection of missile launch by space-based sensors. It may well also require directed-energy weapons which produce beams propagating at or near the speed of light. "Both of those are prohibited by the ABM treaty," reminded a panelist. "It's not as if there's some little, subtle question as to whether a space-based BMD system would be permitted or not. It's not. You can't develop it, you can't test it, you can't deploy it, and it's caught in about eight different places in the treaty. It is not close."
2. **Midcourse BMD.**—The trajectory of a missile reentry vehicle while outside the atmosphere is similar to a satellite orbit: the peak altitude is on the order of 1,000 km and the velocity is slightly suborbi-

tal. There is therefore great overlap between midcourse BMD systems and ASAT systems. The Soviet Galosh ABM system was not designed as an ASAT but does have ASAT capability for satellites in orbits similar to ICBM trajectories; the U.S. miniature homing vehicle ASAT weapon evolved from a design originally intended for midcourse BMD. Since the ABM Treaty strictly limits locations of permitted ABM systems, there are significant constraints, in terms of number and location, on ABM systems which could be used as ASATs. Including the interceptors at test ranges, each side would have only about 115 interceptors and they would be located between 45 and 60 degrees latitude. ABM systems permitted under the treaty are therefore "important for some kinds of satellites in certain kinds of orbits, in certain places," but they are "probably not a very significant threat" to satellites in general. In addition to the constraints in the ABM treaty, midcourse BMD (like boost-phase BMD) would probably be inhibited by an effective ASAT treaty.

3. **Terminal BMD.**—BMD systems which attack missile warheads after the warheads have re-entered the Earth's atmosphere have the least overlap with ASAT technology. They are also not very useful systems for defending large areas, as opposed to selected hardened targets. While research into terminal BMD systems is proposed as part of the Reagan administration's Strategic Defense Initiative, they are not the systems primarily responsible for the renewed interest in ballistic missile defense pursuant to the President's March 23, 1983 "Star Wars" speech.

ROLES

Since ASAT and BMD technologies are so closely related, the outcome of any ASAT limitation or testing ban will almost certainly impede midcourse and boost-phase BMD development. Conversely, technology development ostensibly for an advanced ASAT system might provide a loophole for undertaking BMD research which would be in violation of the ABM treaty.

At the same time, the development of high-quality ASATs which will probably occur in the absence of an ASAT agreement would put the space-based elements of any BMD system (sensors if not weapons) at risk. Unconstrained ASATs would threaten sensors even for ABM systems which are within the scope of the present ABM treaty.

PERCEPTIONS

As noted above, aggressive ASAT development will aid development of advanced BMD systems since technologies investigated for ASAT may be useful in either role. ASAT development may therefore be perceived as supporting a BMD program. To the extent that development of BMD is seen as being threatening, ASAT development may likewise be perceived to be a threatening act.

In a political context, a participant suggested that some of the hostile implications of pursuing BMD research might be ameliorated by simultaneously pursuing some sort of space behavior or "rules of the road" agreement.

DRAFT ASAT TREATIES

The 1983 Soviet draft ASAT treaty includes a subtlety of language which may or may not have been intended. The phrase "space object" is a negotiator's "term-of-art" originating with the Outer Space Treaty negotiations. It stands for anything in space except for ballistic missile reentry vehicles, which were purposely and carefully exempted from the jurisdiction of that treaty. Although the Soviet draft mentions space objects in the introduction, an operative article prohibits testing and deploying "space-based weapons for the destruction of objects on the Earth, in the atmosphere, or in outer space" (emphasis added). It does not say "**space** objects," implying that attacks on reentry vehicles would not be excluded from the ban. One participant, noting that the "Soviets are not dummies when it comes to treaty language," thought that quite possibly they intended to use language that was "opaque as to their views" which would "invite us to reveal our views of some of these substantive matters through the route of fiddling around with these language details."

The draft ASAT treaty proposed by the Union of Concerned Scientists, on the other hand, prohibits attacks on "space objects" and therefore does not address the problem of attacks on reentry vehicles. That exemption was made because the ABM problem had been explicitly addressed in the 1972 ABM treaty. "There is a tendency in drafting treaties to make the treaty stand by itself," commented a panelist. "That should be resisted. Every treaty exists in the milieu of other agreements."

At least one participant disputed the value of preparing drafts outside of an ongoing process of negotiation: "I do not like the idea of people putting out draft treaties on ASAT matters." They are invariably "incomplete" since the text alone does not include any of the history that accompanies a true negotiation process and since the authors are not necessarily official representatives of their governments. The "prejudicial effects" of extant drafts "could probably be dismissed in a couple of weeks," but that time could be put to better use should negotiations be resumed.

TREATY WORDING

The language of the ABM treaty was left "fuzzy" in places, and definitions were not made overly precise, in order to leave a "no-man's-land" surrounding prohibited areas. The hope was that debate would ensue as to whether the "no-man's-land" had been entered before there were any questions of treaty violation. This "noble experiment," however, did not provide the desired results. "It turns out the Soviets are creatively legalistic," interpreted one panelist. "They don't worry about the fuzzy areas. In their view, action in a fuzzy area is permitted because it's not prohibited."

However, the suggestion that the Soviets do not uphold the spirit of a treaty was debated by another panelist. "I don't like to talk about the 'spirit of agreement' because there ain't no such thing." However, this panelist noted that there is significant value in having an operative article in a treaty which states the treaty's general purposes. When circumstances change, forcing development of new understandings in order to maintain the treaty, one can look back on that declaration of intent to make an easy transition. "Here is the agreed purpose that's built into the treaty. Here are the new circumstances that bear on that purpose, and here are the new specific understandings that are needed to modernize" the treaty.

Appendix A

Survivability of Space Capability

All panelists agreed that survivable space capability is important to the United States with or without an ASAT treaty. An irreducible residual ASAT threat will remain under any treaty, making survivability measures essential. Without a treaty, of course, satellites will face dedicated ASAT systems in addition to residual capability, making survivability requirements that much more difficult.

"Survivable space capability" includes measures both to protect and to supplement satellites. U.S. satellites have been hardened against nuclear effects and are spaced so that not more than one at a time should be vulnerable to any one nuclear explosion. Protection includes hardening against radiation, hardening against system-generated electromagnetic pulse (high voltages induced within components by radiation from nuclear explosions), and hardening against other nuclear effects. There are additional protective measures which can and should be applied to satellites to guard against non-nuclear threats. Satellites can be made to evade direct-intercept ASATs or space mines by maneuvering or by interfering with (jamming or confusing) the ASAT's homing sensors. In the absence of an ASAT ban, satellites could conceivably also be given active defenses.

Another way to protect satellites is to proliferate them. Various functions can be distributed on a wide variety of satellites, and duplicate satellites can be orbited. These spares can be left silent until needed and they can be decoyed, making their detection and destruction more difficult. One of the most important motivations for distributing capability is to buy time—it will take much longer to destroy many satellites with shared functions than it will take to destroy any single satellite. Proliferated systems should be simpler and more basic than the full-fledged, highly sophisticated equipment now used in military satellites. Non-space assets such as ground stations would have to be proliferated as well, with the proviso again that the proliferated stations not be as complex as the main ground station.

Satellites can also be replaced by other systems. Today, satellites are used in support of strategic forces but they are not essential. Ground-based radars can be used for early warning. Nuclear detonation detection, besides being proliferated onto many small satellites, can be done for our own warheads by placing transmitters on them, if needed. Tactical theater support now done with satellites can be replaced with a variety of systems —remotely piloted aircraft, sounding rockets, balloons, and low-cost replacement satellites launched on cheap boosters or ICBMs or SLBMs. There are many alternatives to space for functions which are now carried out in space.

Appendix B

Compliance With the 1972 ABM Treaty

The Reagan Administration's recent public allegations of Soviet non-compliance with arms control agreements have drawn much attention. One of these allegations concerned construction of a radar in Siberia which was said to be almost certainly in violation of the 1972 ABM treaty. This radar was discussed at one point in the workshop, and portions of that discussion are described in this appendix.

THE SOVIET RADAR NEAR KRASNOYARSK

According to Articles III and IV of the ABM treaty, ABM radars may be located only at agreed ABM sites or test ranges. Article VI notes that early warning radars may not be constructed except on the periphery of the country and looking outward. Agreed Statement F states that phased-array (electronically steered) radars greater than a specified size may not be deployed except as permitted by Articles III, IV, and VI. It goes on to exempt radars used "for the purposes of tracking objects in outer space or for use as national technical means."

The Soviets are constructing a phased-array radar of greater than the specified size near Krasnoyarsk in central Siberia. The location is not near the periphery of the country and it is not oriented outwards. If it is indeed an early warning or ABM battle management radar, the Soviets are in violation of the ABM treaty. The Soviets claim that the radar is allowable under the exemption in Statement F. Since it is geographically poorly sited to be effective for intelligence (national technical means) purposes, it would have to be a space track radar to be permitted under the treaty.

The administration has charged that this radar "almost certainly" violates the ABM treaty. Others find the issue somewhat less clear. The radar "sort of looks like a duck, and it walks a little bit like a duck, but it doesn't look quite like all the other ducks," in the words of one panelist. "The Soviets say, 'Oh, don't worry. It's not a duck. Notice there are some differences between it and other ducks, and when you hear it later, you'll find out it barks. It doesn't quack.' "

According to a panelist, the signal from a space track radar (a "dog") would be quite different from that of a radar used for ABM battle management (a "duck"). Therefore, the question will presumably be resolved when the radar becomes operational. However, some panelists were not willing to wait that long to find out, and they thought that the administration's announcement was proper. "You can't expect me to look at something that looks like a duck and walks like a duck and tell me it's a dog and I'm supposed to take it on faith. . . . You've got to provide more help than that." They felt that the Soviets were obligated to be more forthcoming about the radar than they had been within diplomatic channels, and that the public announcement served notice that the United States feels the issue has not adequately been resolved. Other panelists felt that existing channels were the appropriate forum and that the public announcement did not serve any constructive purpose.

Some panelists were generally skeptical as to whether the radar is in fact in violation of the ABM treaty. The utility of having such a flagrantly illegal early-warning radar, if it is one, was not felt to be sufficient incentive for the Soviets to unilaterally abrogate the ABM treaty. Others, including some who had access to intelligence data, had little doubt that the radar is indeed optimized for the ABM role. The alternative to being an illegal ABM radar is for the radar to be for tracking satellites, indicating a buildup of the Soviet space monitoring capability and being at least suggestive of an extension of their ASAT program.

BREAKOUT FROM AND LOOPHOLES IN THE ABM TREATY

The ABM treaty is under a great deal of pressure. In the United States, no ongoing research, development, or deployment contradicts treaty provisions. However, deployment of ballistic missile defense beyond the permitted single site would violate the ABM treaty, as would development, testing, or deployment of any ABM systems or components other than fixed, land-based ones. A panelist estimated that at the time of President Reagan's March 23, 1983 "Star Wars" speech, U.S. research into ground-based BMD components was about three years away from the point at which continuation could have run up against the ABM treaty. In light of the March 23 speech and ensuing developments, this estimate may be lengthened to about a decade because more futuristic BMD technologies, which are highly immature, presumably will be emphasized at the expense of the older, more developed systems which were closer to deployment.

The Soviets, according to articles in *Aviation Week and Space Technology* referred to by workshop participants, are building defenses against tactical ballistic missiles. Since the ABM treaty prohibits defenses only against **strategic** missiles, anti-tactical ballistic missile (ATBM) systems are not covered and are therefore permitted. Anti-tactical ballistic missiles were not included in the ABM treaty at United States insistence in order to protect SAM-D, a surface-to-air missile then under development which was intended to have some capability against short-range tactical ballistic missiles as well as against aircraft. However, according to a panelist, as SAM-D developed (changing its name to 'Patriot'), "it lost not only its capability against missiles, but it lost much of its anti-aircraft capability" as well. At the same time, "the Soviets have essentially designed and deployed the 'SAM-D-ski', which looks a lot like what we were trying to protect."

ATBM systems, and their impact on the continuing viability of the ABM treaty, were a source of considerable concern to many panelists. A panelist felt that "if things are deployed under the rubric of anti-tactical ballistic missiles, they can or will have an impact on the penetrability of our SLBMs and the French deterrent system and the British deterrent system, and the whole ball of wax can unravel." The U.S. deployment of Pershing II missiles in Europe could stimulate a particularly troubling Soviet ATBM deployment. "The United States has no excuse for deploying anti-tactical ballistic missiles in its homeland," pointed out a participant, "but the Soviet Union does—and we're giving them a better one. We are now deploying an offensive system that says, 'Hey, you know those ATBMs? Come on, bring them out, there's a legitimate use for them now.' "

Panelists did note that, even if the Soviets should deploy extensive ATBM systems, it need not change the strategic balance. "We know how to deal with them," said one. "It requires penetration aids. We know how to do that." These aids are not presently deployed in the strategic inventory, which "we ought to do something about," but the United States is not in imminent danger of being effectively disarmed.

Another cause for concern is the continued miniaturization of components. Those who worry about possible scenarios in which the Soviet Union builds and stockpiles components in preparation for rapid breakout from the ABM treaty are worrying more now because small radars can have enough capability to fulfill some ABM roles. Even so, small radars cannot do so in the absence of large phased-array battle management radars. Since ABM battle management radars and space track radars share at least some characteristics, panelists felt that a radar clause might be required in an ASAT agreement to prevent circumvention of the ABM treaty restrictions on radars.

Workshop on Arms Control in Space
January 30-31, 1984

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NOTE: Several participants were originally invited as alternates for others who could not attend the entire workshop.

Space Policy:
High School Debate Bibliography

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February 1990

INTRODUCTION

This bibliography contains annotated citations to journal articles, books, and government documents on the topic of United States Space Policy. Items were drawn primarily from the Library of Congress computerized catalog, the Congressional Research Service (CRS) Public Policy Literature database (PPLT), Public Affairs Information Service (PAIS), National Technical Information Service (NTIS), and the Catalog of the National Aeronautics and Space Administration library.

This bibliography is divided into four major sections, representing the general debate topic and the three specific resolutions. The first section includes general materials, ranging from books outlining space policy, space law, international cooperation in space, and other issues. The second section includes material on exploration, both human and robotic, and issues surrounding space exploration. The third section includes material on commercial space activities, including satellites, industrial uses of space, spinoffs, private launch options, and other issues. Finally, the fourth section addresses the issue of militarization of space, including the Strategic Defense Initiative.

The resolution of this year's debate topic are closely interrelated; debaters are therefore encouraged to study the materials in all categories. Some examples of overlap include the space shuttle, the space station, and international cooperation in space.

This bibliography is not intended to serve as a comprehensive list of all resources in the field of space policy. It is merely an introductory guide to materials available on the debate topic. Many of the items included in this bibliography contain footnotes or their own bibliographies; these can be effective tools for finding supplementary material. More information on all of these subjects can be obtained through library research; a CRS-prepared research guide follows the bibliography, with basic information for finding additional material. Search terms and strategies for research are provided in that guide, as are descriptions of basic resources for information retrieval. In addition, the research guide includes citations to reference sources in the area of space policy.

CONTENTS

GENERAL 582

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE SPACE EXPLORATION 607

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE COMMERCIAL DEVELOPMENT OF SPACE 633

RESOLVED: THAT THE UNITED STATES GOVERNMENT SHOULD SIGNIFICANTLY INCREASE ITS MILITARY USE OF SPACE 666

GENERAL

AAS Conference (29th: 1982: Houston, Tex.)
Developing the space frontier: proceedings of the 29th AAS Annual Conference, held October 25-27, 1982, in Houston, Texas. Edited by Albert Naumann and Grover Alexander; cosponsored by the American Institute of Aeronautics and Astronautics. San Diego, Calif., Published for the American Astronautical Society by Univelt, c1983. 419 p. (Advances in the Astronautical sciences, 0065-3438; v. 52)
Includes bibliographical references and indexes.

An Agenda for the 21st century. Compiled by Rushworth M. Kidder. Cambridge, Mass., MIT Press, 1987. 216 p.
Interviews with Mortimer Adler, Sissela Bok, Shuichi Kato, Michael Hooker, Norman Cousins, Barbara Tuchman, Paul Johnson, Hanna Gray, Amitai Etzioni, Marina Whitman, Douglas Fraser, Robert McNamara, Abdus Salam, Freeman Dyson, Theodore Gordon, David Packard, Lloyd Richards, Andrei Voznesensky, Carlos Fuentes, Olusegun Obasanjo, Jimmy Carter, and Richard von Weizsacker. Originally published as a series in the Christian Science Monitor.

Aeronautics and space report of the President: 1987 activities. Washington, National Aeronautics and Space Administration, 1989. 182 p.
This is the most recent in a series of reports with the same title and issued annually. Includes descriptive information about elements of the U.S. space program, interagency programs, and budgetary information.

Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, prepared at the request of Hon. Howard W. Cannon, Chairman, Committee on Commerce, Science, and Transportation, United States Senate. Washington, G.P.O., 1980. 3 v.
At head of title: 96th Congress, 2nd session. Committee print.

Alternative space futures and the human condition: UNISPACE 82 International Round Table, edited by Kiran Karnik. Oxford, Oxfordshire, New York, Published for the United Nations by Pergamon Press, c1982. 175 p.

America in perspective: major trends in the United States through the 1990s. Edited by Daniel Heath. Boston, Houghton Mifflin, c1986. 394 p.
"Revised and updated report of a study commissioned in 1981 by American Express, Bristol-Myers, and Sun Oil."

America's future in space. Roll call, v. 34, Apr. 17-23, 1989, suppl.: 1-27.
Partial contents.--Twenty-eight years after Kennedy.--The unanswered questions.--How do we fund the space program?--Free market alone won't develop space commerce.

America's return to space. Newsweek, v. 112, Oct. 10, 1988: 22-29, 31, 33, 35-38.
Contents.--'Liftoff, liftoff,' by Geoffrey Cowley.--After the Challenger, by Jerry Adler.--Why are we up there? by Melinda Beck.

America's transition: blueprints for the 1990s. Edited by Mark Green and Mark Pinsky. New York, Democracy Project, c1989. 591 p.
"The 58 policy leaders writing in America's Transition describe how a fair and frugal government can improve the quality of our lives. Threaded throughout the 38 chapters are five pre-eminent values that provide the foundation of all the individual proposals. Taken together, these values--strong democracy, demand-side growth, children first, post-cold war peace and respect for law--form the foundation of a progressive governing agenda as much at odds with prevailing conservative orthodoxy as Copernicus was from Ptolemy."

American Agenda (Organization)
Report to the forty-first President of the United States of America. Washington, The Agenda, 1988. 2 v. (ca. 140, ca. 55 p.)

Report of a nongovernmental organization cochaired by former Presidents Ford and Carter offers recommendations for specific policy priorities and actions . . . taken early in the next administration. In the first volume are a personal message and a perspective on Presidential priorities by Ford and Carter. Next are separate panel reports on economic policy by Paul O'Neill, Alice Rivlin, W. Michael Blumenthal, and James Robinson III; domestic policy (Carla Hills, Edmund Muskie, Vernon Jordan, Glenn Watts, and Lamar Alexander); defense and arms control (Brent Scowcroft and R. James Woolsey); and Presidential decision-making (Donald Rumsfeld, Robert Strauss, and Stuart Eizenstat). The remainder of volume one and all of volume two contain commentaries on current and future issues by Robert Hormats (trade, Third World debt), Peter Wallison and John Petty (thrift crisis); Isabell Sawhill (poverty and the underclass), Lee Dogoloff (drug abuse), Ernest Boyer and Terrel Bell (education), Alexander (education), Alvin Alm (environment), Robert Blackwill (relations with European allies),

American Association for the Advancement of Science. Project 2061.
Science for all Americans: a Project 2061 report on literacy goals in science, mathematics, and technology. Washington, The Association, 1989. 217 p.

"Project 2061 involves a three-phase plan of purposeful and sustained action that will contribute to the critically needed reform of education in science, mathematics, and technology." Recent studies have shown that the U.S. education system is failing to impart scientific literacy--knowledge of science, mathematics and technology.

An American vision: policies for the '90s. Edited by Edward H. Crane and David Boaz. Washington, Cato Institute, c1989. 358 p.

Anthology of 21 articles "divided into three general sections on the economy, foreign policy, and domestic policy and a small concluding section on the Constitution and liberty. An overriding theme that weaves its way through each section is . . . the 'unintended consequences' of government intrvention. No matter how benign the intentions, government intervention--in the domestic economy, overseas, or dealing with personal choices--involves coercively structuring human relations."

Australia and space--a bicentennial perspective. Journal of the British Interplanetary Society, v. 41, Dec. 1988: 537-628.

Partial contents.--A policy for space industry development, by B. S. Middleton.--Space science in Australia, by J. G. Greenhill.--Two hundred years of astronomy in Australia, by J. G. Robertson.--An overview of remote sensing activities in Australia, by B. C. Forster.--The Cape York international spaceport project, by G. H. S. Pike.--The development of a space capability within Australian industry, by T. E. Stapinski

Bainbridge, William Sims.
The spaceflight revolution: a sociological study. New York, Wiley, c1976. 294 p.

This work was reprinted in 1983 by Krieger.

Baker, David.
NASA explores the high frontier. New scientist, v. 119, Sept. 29, 1988: 60-64.

"Thirty years ago . . . NASA opened its doors for business. Since then it has put six astronauts on the Moon and sent robots to every planet but one in the Solar System. The agency must now look for a new long-term policy."

Banks, Peter M. Ride, Sally K.
Soviets in space. Scientific American, v. 260, Feb. 1989: 32-40.

Describes the Soviet space program, its accomplishments, plans, and the long-range political and financial commitment to it.

Barrett, Eric.
Satellite remote sensing needs and applications in less developed countries. Space education, v. 1, June 1983: 211-215.

Sketches how satellite gathered data can be used for the benefit of less developed countries.

Bell, Trudy.
Space: is it worth it? Space world, v. R-4-208, Apr. 1981: 17-20, 25-26.

"Space is a resource, as precious as air, water and earth. Proper use of the space resource has already--and can continue--to help ameliorate ills here on Earth, financially, materially, and to an extent even socially."

Bellavita, Christopher.
Public policy, organization theory and space stations. Policy studies review, v. 7, winter 1987: 275-289

"This paper builds on the link between public policy and organization theory by describing the culture of U.S. space station policy. The paper discusses space station policy, the concept of a 'policy organization,' and the relationship between culture and public policy. The major assumptions of three subcultures in the space station policy organziation are identified and illustrated. The paper concludes with a discussion of some implications of the cultural perspective for future space policy."

Biddle, Wayne.
NASA: what's needed to put it on its feet? Discover, v. 8, Jan. 1987:31-34, 36, 40-41, 44-45, 48-49.

Contends that "the space program lacks realistic long-term goals and the sense of initiative they could reawaken. Worse, it seems to lack the leadership needed to formulate such goals and sell them to those who control the money in Washington or to the American people."

Bisplinghoff, Raymond L.
The effects of the space programme in stimulating education, science and engineering. In United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 1968. Space exploration and applications. New York, United Nations, 1969. p. 1262-1269.

Blaine, James Cyril Dickson.
The end of an era in space exploration: from international rivalry to international cooperation. San Diego, Calif., American Astronautical Society; distributed by Univelt, c1976. 199 p. (Science and technology series; v. 42)

Bless, Robert.
Space science: what's wrong at NASA. Issues in science and technology, v. 5, winter 1988-89: 67-73.

Using the Hubble Space Telescope as an example, the author points out what is wrong with how NASA conducts space science. The problems are: "overreliance on the space shuttle, a predilection for big projects, and poor management."

Bova, Ben.
Three fallacies. Omni, v. 4, Oct. 1981: 66-68, 174.

"Most of the people who doubt the usefulness of the space program fall victim to one or more of three fundamental fallacies: the Flat Earth Fallacy, the Either/Or Fallacy, or the Manana Fallacy. Each is dangerous."

Bradshaw, Jeremy.
Space for wildlife. New scientist, v. 100, Nov. 10, 1983: 410-413.

"The greatest rocket launching site on Earth is the last place you would expect to find a thriving wildlife community. But the land surrounding the Kennedy Space Center in Florida is a sanctuary for more threatened and endangered species of wildlife than any other refuge in mainland US."

Brodsky, Robert F. Morais, Bernard G.
Space 2020: the technology, the missions likely 20-40 years from now. Aeronautics & astronautics, v. 20, May 1982: 54-73.

Sets out what could happen in space in the next 40 years. Foresees continued development of the military uses of space, further exploration of the solar system and manufacturing in space.

Brown, George.
International cooperation in space. Space policy, v. 3, Aug. 1987: 166-174.

The author, a democratic Congressman from California, advocates directing space activities to uses such as arms verification, environmental monitoring, international cooperation on space missions, and an international mission to Mars.

Brown, Seyom, and others.
Regimes for the ocean, outer space, and weather. Washington, Brookings Institution [1977] 257 p.

"This study is an examination of the problems of scarcity, an assessment of the possibilities for regulating resource use, and a proposal. The authors suggest that new international agencies be established to coordinate the disparate private and governmental activities affecting the oceans, the atmosphere, extraterrestrial space, and the weather. Only thus, they argue, can the exploitation of limited, essential resources be controlled so as to promote the general welfare of the earth's inhabitants."

Brown, Stuart F.
20 years after Apollo: is the U.S. lost in space? Popular science, v. 235, July 1989: 63-64, 66, 68-75.

Presents a series of interviews with experts in U.S. space research and programs on the present state of U.S. space policy.

Budget effects of the Challenger accident. Washington, Congressional Budget Office, 1986. 17 l.

"Procurement of a new orbiter, more costly shuttle operating procedures, and the space station program could require an additional $1 billion in NASA's annual budget through 1990. The Congress will be concerned about the budgetary effects of these issues not only in 1986 and 1987 but also well into the next decade, calling into question the future federal role in the commercial and scientific development of space."

Budget of the United States Government; fiscal year 1991. Washington, For sale by the Supt. of Docs., G.P.O., 1990. 1269 p.

"This single volume, the Budget of the United States Government, Fiscal Year 1991, replaces several publications previously issued by the Office of Management and Budget."

The annual Budget of the United States Government contains the Budget Message of the President and presents an overview of the President's budget proposals. It includes summary information on goals of the annual budget, economic assumptions, receipts and outlays and various summary data tables.

Canby, Thomas F.
A Generation after Sputnik: are the Soviets ahead in space? National Geographic magazine, v. 170, Oct. 1986: 420-458.

Cetron, Marvin. Davies, Owen.
American renaissance: our life at the turn of the 21st century. New York, St. Martins Press, 1989. 400 p.

Cetron, Marvin J. Rocha, Wanda. Luckins, Rebecca.
Into the 21st century: long-term trends affecting the United States. Futurist, v. 22, July-Aug. 1988: 29-40.

Discusses 71 societal trends, emphasizing that the U.S. educational system must be improved in order to compete in the global economy. Recommends greater entrepreneurism, right-to-work laws, and a higher retirement age. Claims that "the U.S. must overcome the 'bottom line' syndrome that pervades society, causing both government and citizens to set their sights on short-term profits at the expense of the nation's future." Labor trends include a growing service sector, a decline in manufacturing jobs, declining unionization, more women and minorities in the labor force, more midlife career changes, and a shortage of low-wage workers.

Clark, David H.
The cosmos from space. New York, Crown Publishers, 1987. 162 p.

Collins, Michael.
Carrying the fire: an astronaut's journey. New York, Farrar, Straus, and Giroux, 1974. 462 p.

Liftoff: the story of America's adventure in space. New York, Grove Press, 1988. 288 p.

Colloquium on the Law of Outer Space, 18th, Lisbon, 1975.
Proceedings. South Hackensack, N.J., Distributed by Fred B. Rothman & Co., 1976. 201 p.

Papers were presented on the legal aspects of the utilization of energy from space, the legal status of geostationary orbit, and general questions of international legal cooperation in astronautics.

Colloquium on the Law of Outer Space, 19th, Anaheim, Calif., 1976.
Proceedings. South Hackensack, N.J., Distributed by Fred B. Rothman & Co., 1977. 419 p.

Papers and discussion covered the future of space law, space law and energy, space colonies, remote sensing, and direct broadcasting by satellite.

Colloquium on the Law of Outer Space, 21st, Dubrovnik, 1978.
Proceedings. Davis, University of California, School of Law, distributed by F. B. Rothman, 1979. 291 p.

Contains papers presented at the International Aeronautical Federation's 21st Colloquium on the Law of Outer Space, the theme of which was "Astronautics for Peace and Human Progress." Topics discussed included telecommunication, remote sensing, solar energy and delimitation (definition) of outer space. Three articles are in French.

Colloquium on the Law of Outer Space, 27th, Lusanne, Switzerland.
Proceedings. New York, American Institute of Aeronautics and Astronautics, c1985. 413 p.

International Institute of Space Law conference held Oct. 7-13, 1984, Lusanne, Switzerland.

Colombo, Giuseppe.
Space technology: where will fiction meet reality? Technology review, v. 84, Oct. 1981: 69-77.

"The fact that we have not yet undertaken many technically feasible projects to bring the resources of space to bear on our urgent needs on earth suggests that the line between reality and fiction depends not on science but on social and political factors."

Committee on Space Policy.
Towards a new era in space: realigning US policies to new realities. Space policy, v. 5, Aug. 1989: 237-255.

"The US National Academies of Science and Engineering in early 1988 formed a committee of experts in science, economics, engineering and business to recommend to the incoming government policies to guide the US space programme over the long term. This article contains the committee's conclusions and recommendations, which concentrate on the leadership role of the President and the need for a stable budgetary policy distinguishing between a base programme and special initiatives--of which the Space Station would be one."

Compton, W. David. Benson, Charles D.
Living and working in space: a history of Skylab. Washington, Scientific and Technical Information Branch, National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1983. 449 p. (NASA history series NASA SP-4208)

"The origins and evolution of the Skylab project are traced. Some of the topics covered in this work are the Skylab program organization, congressional and budgetary matters concerning Skylab, astronaut training, the science projects conducted on Skylab and their results, and the spacecraft's reentry in July 1979.

Cook, William J.
The new frontiers. U.S. news & world report, v. 105, Sept. 26, 1988: 50, 52-53, 56-58, 60-61.

Describes four complicated space missions developed by NASA's Office of Exploration that will be reviewed by the next Administration for possible implementation: a manned trip to Mars, a manned flight to Phobos, deploying telescopes on the far side of the moon, and building a space station.

Cooper, Earl D. Shaker, Steven M.
Soaring into the next century: new directions for U.S. aerospace. Journal of defense & diplomacy, no. 4, Sept. 1988: 28 p.

Contents.--Aerospace policy: government and industry relationships.--Global and U.S. domestic trends.--Technology forecast.--Military aviation.--Space.--Commercial aviation.--Overall aerospace summary and conclusions.

Corrigan, Richard.
NASA's midlife crisis. National journal, v. 18, Mar. 22, 1986: 686-692.

"NASA's can-do spirit has been undermined by leadership squabbles, low morale and the prospect of extended delays for cherished projects because of the shuttle explosion."

Cowen, Robert C.
Space: where next for the US? Christian Science monitor, Dec. 27, 1983, p. 16-17; Dec. 28: 14-15; Dec. 29: 14.

Contents.--NASA-ripe for a renaissance.--A new agenda for NASA beyond the pioneering stage.--Building a permanent presence in orbit--a laboratory/service station/factory.

A Crisis in the NASA space and Earth sciences programme. Space policy, v. 3, Feb. 1987: 38-51.

"The US space and Earth sciences programme is in a time of crisis. As the research environment changes and new scientific opportunities emerge, a broader range of resources is needed, including substantial new flight opportunities. There are a growing number of claimants for space research resources. Fluctuations in funding, programme delays and mismatched time scales have contributed to wasted time and research efforts."

Culbertson, Philip E. Freitag, Robert F.
The partnership: space shuttle, space science and space station. [Washington?] National Aeronautics and Space Administration [1986] 12 p.

Dembling, Paul G.
International liability for damages caused by the launching of objects into outer space--theory and applications. In United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 1968. Space exploration and applications. New York, United Nations, 1969. p. 1116-1120.

Dentzer, Susan.
The Peace outbreak sparks a war on defense spending: contractors and the U.S. economy face a shakeout. U.S. news & world report, Dec. 4, 1989: 51-52.

Finds that, though the long-run effect of defense spending cuts could be a boon to the economy, in the short-run the "costs could be pronounced . . . . Defense companies now face the prospect of competing for shrinking contracts or converting to new lines of business. And for many workers, the much ballyhooed 'peace dividend' might be more like a peace dole."

Department of Veterans Affairs and Housing and Urban Development and Independent Agencies Appropriations Act, 1990; floor debate. Congressional record [daily ed.], v. 135, July 20, 1989: H3959-H4012.

Included in this debate is the Roe amendment "that earmarks $98 million for the National Aerospace Plane" and the "Schumer amendment that sought to transfer $714 million from the space station to other programs, including: Veterans' Medical Services, EPA Pollution Control and Research, Low-Income Rental Housing Certificates and Elderly and Handicapped Housing (rejected by a recorded vote of 125 ayes to 291 noes, Roll No. 146)."

Deudney, Daniel.
Space: the high frontier in perspective. Washington Worldwatch Institute, 1982. 72 p. (Worldwatch paper 50)

Reviews a quarter century of space activities and highlights future space programs. Warns of the increasing danger of space warfare.

Dickson, Paul.
How a little beep-beep-beep scared America half to death. Washingtonian, v. 17, Sept. 1982: 117, 119-120, 122-124, 126-128.
"Sputnik was a little satellite the size of a beach ball, but in 1957 it seemed to signal an end to our way of life."

Drexler, Eric.
America in space: boondoggle past, ho-hum present, ephemeral future. CoEvolution quarterly, no. 29, spring 1981: 18-23.
"Lightsails can cut the cost of getting around in space by perhaps a factor of 1000. The riches of space, both energy and materials, seem within reach at last, yet NASA teeters on with declining budget and aging upper echelons pouring everything into an under-funded, half-reusable Shuttle while their best people abandon ship."

Easterbrook, Gregg.
Lost in space. Washington monthly, v. 19, Apr. 1987: 48-54.
Two recent books, "Challenger: a Major Malfunction," by Malcolm McConnell and "Prescription for Disaster," by Joseph Trento show how poorly the major media have covered the institutional decline of NASA.

The Economic and budget outlook: fiscal years 1991-1995; a report to the Senate and House Committees on the budget--part 1. Washington, U.S. Congressional Budget Office, For sale by the Supt. of Docs., G.P.O., 1990. 151 p.
Contents.--The economic outlook.--The budget outlook.--Baseline spending, revenue, and credit projections.--Analysis of congressional budget estimates.--Concepts and assumptions underlying the CBO budget baseline.--Baseline spending and credit projects by budget function.--Federal receipts and expenditures in the national income and product accounts.--Historical budget data.2--Major contributors to the revenue and spending projections.

Eisenhower, Milton S.
Facing America's problems: a call for action. USA today, v. 110, July 1981: 22-24.
President Eisenhower's brother recommends reforms to help the U.S. solve its problems: a limit on the terms of both Congressmen and Presidents, and lifelong education for critical, creative, and effective citizenship.

Elmandjra, Mahdi.
The conquest of space: a few political, economic and sociocultural considerations. Third World quarterly, v. 6, July 1984: 576-603.
Sees space exploration as a dualism because it can be "an instrument of power and destruction, and even extermination, on the one hand, and on the other, space could be a factor of progress." Contends that only a few countries with sufficient resources will be able to conquer space while most nations will be consumers of space spin-offs.

Emme, Eugene M.
Space and the historian. Spaceflight, v. 15, Nov. 1973: 411-417.

Ervin, Scott.
Law in vacuum: the common heritage doctrine in outer space law. Boston College international and comparative law review, v. 7, summer 1984: 403-431.
"This Comment focuses on the difficulties the world community has had in interpreting and applying space law principles. In particular, the author discusses the problems arising from states' differing interpretations of the principles of freedom of outer and the principle of common heritage. The author explores the viability of these principles in the context of current political and economic world realities and suggests that the principles may yet become functional rules of international law."

Etzioni, Amitai.
Social progress vs. economic progress. Social policy, v. 10, Mar.-Apr. 1980: 4-9.

European Space Symposium (18th: 1983: London, England)
Space, a developing role for Europe: 18th European Space Symposium. Edited by L. J. Carter and Peter M. Bainum. San Diego, Calif., Published for the American Astronautical Society by Univelt, c1984. 268 p. (Science and technology series, 0278-4017; v. 56)

Ezell, Edward Clinton. Ezell, Linda Neuman.
The partnership: a history of the Apollo-Soyuz Test Project. Washington, Scientific and Technical Information Office, National Aeronautics and Space Administration, 1978. 560 p. (U.S. National Aeronautics and Space Administration. NASA SP-4209 U.S. National Aeronautics and Space Administration. NASA history series)

Ezell, Virginia H.
Japan's space program takes off. Journal of defense & diplomacy, v. 6, Oct. 1988: 16-19.
Reports on Japan's expanding space program.

Farrell-Gisse, Katrina. Gimlin, Hoyt.
American options in space. Washington, Congressional Quarterly, 1983. 131-148 p. (Editorial research reports, 1983, v. 1, no. 7)

Feynman, Richard P.
An outsider's inside view of the Challenger inquiry. Physics today, v. 41, Feb. 1988: 26-37.
The author recounts his experiences and impressions of serving on the Rogers Commission which investigated the Challenger space shuttle accident.

Field, George B.
Astronomy and astrophysics for the 80s. Astronautics & aeronautics, v. 20, Apr. 1982: 44-51.
"Major new space and ground instruments recommended by the NAS National Academy of Sciences] Astronomy Survey Committee would sweep the amazing frontiers opened in the past two decades."

Finn, Daniel P.
Nuclear satellites: why has the Government downplayed their risks? Environment, v. 26, Jan.-Feb. 1984: 14-20, 39.
Warns of the danger of radioactive debris reaching Earth's surface when nuclear powered artificial satellites re-enter the Earth's atmosphere.

The First 25 years in space: a symposium. Edited by Allan A. Needell. Washington, Smithsonian Institution Press, c1983. 152 p.
"Section one addresses the motivations for going into space and how they have changed over the past 25 years; . . . section two emphasizes the economic significance of space activities, and suggests how those activities might be organized, managed, and supported in the future; . . . section three considers the scientific component of the push into space."

Ford Foundation. Project on Social Welfare and the American Future. Executive Panel.
The common good: social welfare and the American future: policy recommendations. New York, The Foundation, 1989. 102 p.

Friedberg, Aaron L.
The making of American national strategy, 1948-1988. National interest, no. 11, spring 1988: 65-75.
Asserts that "over the last forty years there have been no fewer than thirteen separate attempts at broad, national (as compared to service-specific or narrowly problem-specific) strategic planning." Examines how such efforts have been conducted, and what they have accomplished, and what can be expected from any such attempts in the future.

Friedman, Herbert.
Perspectives on space science. Astronautics & aeronautics, v. 14, Jan. 1976: 24-28.
The Director of the E. O. Hulburt Center for Space Research, Naval Research Laboratory outlines the benefit and promise of the U.S. space sciences program.

Furniss, Tim.
Space Shuttle. Flight international, v. 127, June 22, 1985: 34-37.

"Launch delays and . . . cancellations, have focused attention on the complex process of turning Space Shuttle around between flights. As NASA aims for two missions a month by 1987, Tim Furniss reports from Kennedy Space Centre, Florida, in . . . three articles on Orbiter, payload, and launch processing at KSC."

Contents.--Turning Shuttle around.--Handling Shuttle's cargo.--Launching Shuttle.

Garwin, Richard L. Gottfried, Kurt. Hafner, Donald L.
Antisatellite weapons. Scientific American, v. 250, June 1984: 45-55.

Glaser, Peter E. Brender, Mark E.
The First Amendment in space: news gathering from satellites. Issues in science and technology, v. 3, fall 1986: 60-67.

"Within the next decade news organizations could be able to take pictures from advanced remote-sensing satellites of any place on earth, producing images of extraordinary detail. This new dimension of news gathering--the product of gradual changes in technologies such as optics, data processing, and computer image enhancement--will pose difficult problems in a wide range of policy areas including national security, privacy, and freedom of the press."

Glazer, Sarah.
Space race. Washington, Congressional Quarterly, 1987. 378-391 p. (Editorial research reports, 1987, v. 2, no. 4)

Explores the future direction of the U.S. space program, compares the U.S. and Soviet programs, and discusses the risks and the benefits of manned space flight.

Goedhuis, D.
The present state of international relations in outer space. International relations, v. 7, May 1983: 2284-2303.

Reviews the various political, economic, social, and military problems which have arisen in international relations in outer space in the past 25 years and considers growing economic and military confrontations.

Gordon, Theodore J.
A futurist's view of space. Futures research quarterly, v. 1, fall 1985: 19-27.

Gotlieb, A. E. Dalfen, C. M.
International relations and outer space: the politics of co-operation. International journal, v. 25, autumn 1970: 685-703.

Grey, Jerry.
The aerospace plane: the timing is right. Issues in science and technology, v. 3, spring 1987: 14-24.

Profiles the aerospace plane, "a vehicle that would have some characteristics of both airplanes and rockets. Like an airplane, it could take off from and land on a runway; like a rocket, it could accelerate to speeds necessary to reach low earth orbit."

Grossman, Karl.
Red tape and radioactivity. Common cause magazine, v. 12, July-Aug. 1986: 24-27.

"As tragic as the Challenger catastrophe was, it could have been much, much worse. The shuttle could have been carrying plutonium, the most toxic radioactive substance known. And despite the Challenger explosion, NASA plans to forge ahead with plutonium-fueled space probes."

Hamer, John.
America's next century. Washington Editorial Research Reports, 1976. 23 p. (Editorial research reports, 1976, v. 1, no. 1)

Report looks at the future outlook for Americans as well as the research techniques that may be helpful in forecasting the future.

Hansen, Richard Earl.
Freedom of passage on the high seas of space. Atlantic Community quarterly, v. 16, fall 1978: 345-357.

"Preserving the freedom to operate on the high seas of space is essential to the future well-being of all nations. Securing space for free travel and commerce to the benefit of all, ideally, should be the aim of all the nations of the world," concludes the writer.

Harr, Karl G., Jr.
Space and the national economy. Aerospace, v. 8, Mar. 1970: 2-5.

Heppenheimer, T. A.
The space station nobody wants. Reason, v. 19, Feb. 1988: 22-28.

Author contends that the U.S. space station project was approved on the basis of President Reagan's personal enthusiasm for space. Maintains NASA is pursuing a project which may never be launched, while ignoring the problem of developing reliable launch vehicles.

Hi-tech America. Science digest, v. 93, Mar. 1985: 33-87 passim (24 p.)

Partial contents.--Boom or bust on the new frontier, by M. Rogers.--Space Inc., by R. Martin.

Ince, Martin.
Space. London, Sphere Books, 1981. 215 p.

Space wars: a graphic guide. London, Camden Press, 1986. 171 p. (Graphic guides)

"Explains . . . military and commercial [space] developments and assesses their impact worldwide."

International cooperation and competition in civilian space activities. Washington, Office of Technology Assessment, 1985. 472 p.

"OTA-ISC-239"

"Alterations in the political, economic and technical context of space activities raise four major international concerns for Congress: the state of U.S. competitiveness in space technologies, the role of the U.S. private sector in space, the access of U.S. firms to international markets, and the efficacy of U.S. participation in international cooperative space projects and organizations."

International cooperation in space: how to enhance the results, share the risk. Government executive, v. 16, Feb. 1984: 9, 12, 14.

Sees benefits in international cooperation in space because overseas funding and commitments provide program stability "against 'raids' on the U.S. portion of the commitment by politicians and others who would like to see the budget dollar spent elsewhere from time to time."

International space policy: legal, economic, and strategic options for the twentieth century and beyond. Edited by Daniel S. Papp and John R. McIntyre. New York, Quorum Books, 1987. 328 p.

"Papers originally presented at a conference held at Georgia Institute of Technology, May 16-17, 1985"

Jarvis, Robert M.
The space shuttle Challenger and the future law of outer space rescues. International lawyer, v. 20, spring 1986: 591-621.

"This article is intended to advance the proposition that admiralty law provides many useful precedents for resolving outer space disputes. Given this thesis, the article's purpose is to demonstrate the applicability of admiralty to space law within the particular context of situations in which spaceships and satellites must be rescued."

Johnson, Nicholas L.
The Soviet year in space, 1989. Colorado Springs, Colo., Teledyne Brown Engineering, 1990. 179 p.

Lists and describes Soviet space activities for 1989.

Johnson-Freese, Joan.

Changing patterns of international cooperation in space. Malabar, Fla., Orbit Book Co., 1990.

This work will be available later in 1990.

Jordan, Amos A.

A national strategy for the 1990s. Washington quarterly, v. 10, summer 1987: 15-24.

"The purpose of this essay is to contribute to the process of (re-)articulating a national strategy for the years of challenge ahead. It delineates components of a strategic perspective by defining the concept of strategy and analyzing the ways in which the international environment shapes contemporary choices, advances six strategic propositions for the 1990s, and discusses the problems of resources and the process of making national strategy."

Karp, Aaron.

Space technology in the Third World. Space policy, v. 2, May 1986: 157-168.

Discusses the spread of older missile technology to the Third World and points to the danger that these nations will use satellite launch technology for military applications. Urges establishment of an Internationational Missile Technology Regime to limit the transfer of space launch technology to nations in compliance with the Nuclear Non-Proliferation Treaty.

Keaton, Paul W.

Why billions can and should be spent on space. Astronautics & aeronautics, v. 21, May 1983: 86-88, 90-92.

Contends that "over the next twenty-two years GNP will total about $100 trillion, easily supporting $130 billion for large focused space programs."

Kennan, Erlend A. Harvey, Edmund H., Jr.

Mission to the moon; a critical examination of NASA and the space program. New York, Morrow, 1969. 396 p.

Killian, James R., Jr.

Sputnik, scientists, and Eisenhower: a memoir of the first special assistant to the President for Science and Technology. Cambridge, Mass., MIT Press, c1977. 315 p.

Presents a personal reflection on scientific policy decision making during the Eisenhower years.

Kinahan, Graham.

Soviet intentions in space. Journal of social, political and economic studies, v. 13, fall 1988: 247-250.

Focuses on Soviet space intentions. "A critical examination of their objectives, by policy makers and the press alike, would serve to give strong impetus to our own space program."

Korthals-Altes, Stephen W.

Will the aerospace plane work? Technology review, v. 90, Jan. 1987: 43-51.

Discusses the feasibility of building the military aerospace plane proposed by the Reagan Administration as a successor of the space shuttle and its civilian version, the hypersonic transport (HST). Author concludes that the plane is being oversold since technological challenges are great, the development costs high and its utility limited.

Latham, Donald C.

A prescription for America's galaxy of problems in space. Armed Forces journal international, v. 125, Sept. 1987: 42, 44, 46, 50.

Argues that "the ongoing . . . warfare between DoD, NASA, Department of State, and the Office of Management & Budget must be peacefully negotiated, and the Administration must establish clear-cut management for space policy implementation and space programs across the civilian, civil government, and military sectors."

Lay, S. Houston.
Recent developments in space law. California Western international law journal, v. 9, summer 1979: 514-521.

"Laws relating to the uses of space are evolving into a substantial body of complex and specialized international law that will become increasingly important as the technology of utilizing space develops."

Lepkowski, Wil.
U.S. space policy ready for next big leap. Chemical & engineering news, v. 62, Feb. 1984: 9-16.

Looks at future commercialization of space technology including satellites, research and development in space and the future military uses of space by the U.S.

Lewis, Richard S.
Space in the 21st century. New York, Columbia University Press, c1990.

This work is forthcoming later in 1990.

Library of Congress. Legislative Reference Service.
Treaty on principles governing the activities of States in the explorationand use of outer space, including the moon and other celestial bodies: analysis and background data; staff report. Washington, G.P.O., 1967. 84 p.

Logsdan, Tom.
Future technology: its effect on you. Vital speeches of the day, v. 53, Sept. 15, 1987: 716-722.

Traces what is happening in the technology of computers, robotics, and space exploration, and how young people should be trained to live in a high-tech world.

Logsdon, John M.
The decision to go to the moon: Project Apollo and the national interest. Cambridge, Mass., MIT Press, 1970. 187 p.

Lupton, David.
Space doctrines. Strategic review, v. 11, fall 1983: 36-47.

"After twenty-five years of experience, U.S. space doctrine is still evolving against the background of complex factors . . . . Recent developments . . . are bound to shunt a host of fundamental questions regarding space doctrine to center-stage."

Magnuson, Ed.
Fixing NASA. Time, v. 127, June 9, 1986: 14, 16-18, 20, 23-25.

States that the Challenger disaster, followed by failures of the Titan and Delta rockets, has forced a long-needed reassessment of the goals of the U.S. space program. Calls for presidential leadership in deciding our priorities in space.

Manfredi, Arthur F., Jr.
U.S. space policy: an agenda for debate. National defense, v. 71, July-Aug. 1986: 40-41, 44, 46.

Looks at key issues for the future U.S. space policy, both civilian and military.

Mark, Hans.
The Space Station: a personal journey. Durham, N.C., Duke University Press, 1987. 264 p.

"President Regan's approval of $8 billion for the construction of a permanently manned orbiting space station climaxed one of the most important political and technological debates in the history of the U.S. program in space . . . . Mark, who had major roles in the development of the space shuttle from its beginnings in the sixties and who bore a primary responsibility for overseeing the space station project during the decisive years from 1981 to 1984" discusses the debate.

McDonough, Thomas B.
Space, the next twenty-five years. Revised and updated. New York, Wiley, c1989. (Wiley science editions)

This work will be available later in 1990.

McDougall, Walter A.
The heavens and the Earth: a political history of the space age. New York, Basic Books, c1985. 555 p.

Presents "a narrative history of space activity."

Michaud, Michael A. G.
Reaching for the high frontier: the American pro-space movement, 1972-84. Foreword by Joseph P. Allen. New York, Praeger, 1986. 435 p.

Moeser, John V.
The space program and the urban problem: case studies of the components on national consensus. Washington, Program of Policy Studies in Science and Technology, George Washington University, 1969. 44 p. (Staff discussion paper, 404)

The space program and the urban problem: case studies of the components on national consensus by] John V. Moeser. Washington, Program of Policy Studies in Science and Technology, George Washington University, 1969. 44 p. (Program of Policy Studies in Science and Technology. Staff discussion paper, 404)

Moore, Patrick.
The next fifty years in space. With drawings by Andrew Farmer. London, Luscombe, 1976. 144 p.

A More effective civil space program. CSIS Civil Space Policy Study Group. Washington, Center for Strategic & International Studies, 1989, c1987. 74 p. (CSIS panel reports, 0899-352)

Morrison, David C.
Beyond the blue yonder. National journal, v. 20, Mar. 26, 1988: 798-802.

Mueller, George.
The 21st century in space. Aerospace America, v. 1, Jan. 1984: 84-88.

Describes probable space activities of the 21st century. Foresees weapons in space, communications platforms, space factories and lunar based space activities.

Murray, Bruce.
Civilian space: in search of Presidential goals. Issues in science and technology, v. 2, spring 1986: 25-37.

"Argues that manned space flight can only be justified when the goal is human adventure and exploration. Unmanned flight, Murray says, is a much more cost-effective way to advance science and carry out most other practical activities in space, especially in an era when the capabilities of robots and computers are growing rapidly."

NASA at thirty. Government executive, v. 20, Oct. 1988: 10-12, 15-16, 20-22, 24, 28-29, 78.

Contents.--The space program's mid-life crisis, by Carol Matlack.--The final, far-out things, by Claude Barfield.--The first U.S. space team: John F. Kennedy and James Webb, by Elmer B. Staats.--The NASA story: to the moon and back to earth.

The NASA program in the 1990s and beyond. Washington, Congressional Budget Office, 1988. 85 p.

Examines the options for the U.S. space program for the 1990s and details aspects of the space program and their costs.

NASA space science. Journal of the British Interplanetary Society, v. 41, Jan.-Feb. 1988 whole issue (103 p.)

Partial contents.--Space science at NASA: retrospect and prospect, by Jeffrey D. Rosendhal.--Voyager at Uranus, by Ellis D. Miner and Edward D. Stone.--The sun and the sun-earth connection, by S. M. Krimigis.--The global geospace science programme, by George K. Parks and others.--Looking at the earth from space, by Marvin Geller.

The Next fifty years in space: pioneering the space frontier. Aerospace, v. 24, fall 1986: 2-7.

Summarizes the views offered by the National Commission on Space.

The Next giant leap in space: an agenda for international cooperation; final report. New York, United Nations Association of the United States of America, c1986. 70 p.

"This report represents the consensus of a broad array of Americans on how best to work with other countries to encourage the peaceful explorations and development of" outer space.

National Research Council (U.S.). Committee on Advanced Space Technology.
Space technology to meet future needs. Washington, National Academy Press, 1987. 171 p.

This report, requested by NASA, examines the status of the technology base in advanced space research and technology from the perspective of future needs in space sciences, commercial applications, military needs, and manned exploration. Concludes that the advanced space research and technology program continues to be seriously underfunded and that "little has been done to enhance or develop the basic technologies that will enable future missions or provide the nation with a variety of options for the space program."

National Space Symposium (5th: 1989: Colorado Springs, Colo.)
Space: a new era: report on the fifth national space symposium proceedings sponsored by the United States Space Foundation, April 4-7, 1989, at the Broadmoor Convention Center, Colorado Sprints, Colorado. Edited by Allison P. Kinsley and others. Colorado Springs, Colo., United States Space Foundation, 1989. 275 p.

New instruments for astronomy. Physics today, v. 35, Nov. 1982: 25-33, 36-42, 44-51, 54-59, 60-67.

Contents.--High-energy astrophysics, by G. Clark.--Facilities for US radioastronomy, by P. Thaddeus.--Ultraviolet, optical and infrared astronomy, by E. Wampler.--Contemporary planetary science, by M. Belton and E. Levy.--A golden age for solar physics, by A. Walker.

Newell, Homer E.
Beyond the atmosphere: early years of space science. Washington, National Aeronautics and Space Administration for sale by the Supt. of Docs., G.P.O., 1980. 497 p. (NASA history series)

"NASA SP-4211"

Partial contents.--The meaning of space science.--Prophets and pioneers of spaceflight.--Response to Sputnik: the creation of NASA.--The universities: allies and rivals to NASA.--Space science and practical applications.--Objectives, plans, and budgets.

Oberg, James E.
Red Star in orbit. New York, Random House, c1981. 272 p.

Presents a history of the Soviet space program.

O'Neill, Gerard K.
2081: a hopeful views of the human future. New York, Simon and Schuster, 1982. 284 p.

Organizing space activities for world needs. Edited by Ernst A. Steinhoff. [1st ed.] Oxford; New York, Pergamon Press, 1971. 490 p.

Pedersen, Kenneth S.
The changing face of international space cooperation. Space policy, v. 2, May 1986: 120-137.

Examines NASA's activities and policies over the past twenty years, particularly with regard to international participation in its programs. Discusses recent trends in international cooperation, especially in the space station program.

Post-Challenger assessment of space shuttle flight rates and utilization. Prepared by a panel convened by the Committee on NASA Scientific and Technological Program Reviews, Commission on Engineering and Technical Systems, National Research Council. Washington, National Academy Press, 1986. 52 p.

This study "is in response to a Congressional request in the aftermath of the Challenger accident, for an assessment of possible space shuttle flight rates and their implications in respect to payloads and the need for expendable launch vehicles."

Pournelle, Jerry.

The decisive frontier: space. Omni, v. 4, Nov. 1981: 30, 138-139.

"Before the end of this century--probably in this decade--space weapons will end the balance of terror that has made nuclear war all but unthinkable for the last 36 years. They will make possible a global conflict whose undamaged victor could dictate terms to a disarmed and helpless loser."

Reston, James.

What's the national interest? New York times, pt. 4, Mar. 16, 1986: 25.

Contends that policy-makers have focused on issues like aid for the Contras, rather than the larger question of what is America's national interest.

Robinson, George S.

Who owns the moon? Foreign Service journal, v. 58, July-Aug. 1981: 22-25.

"In the evolution of space law, too many nations and people believed in an effective and successful ambience of cooperation for peaceful purposes in near- and deep-space activities. It distracted some of the decision-makers from proper considerations of the true military, economic, political, and ideological motivations of the primary space-law negotiators."

Romzek, Barbara S. Dubnick, Melvin J.

Accountability in the public sector: lessons from the Challenger tragedy. Public administration review, v. 47, May-June 1987: 227-238.

Contend that "the pursuit of political and bureaucratic accountability distracted NASA from its strength: professional standards and mechanisms of accountability."

Rowberg, Richard E.

Science, technology, and public policy. Congressional Research Service review, v. 11, Jan.-Feb. 1990: 13-14.

"Increasingly, science and technology are bounding the set of public policy options, acting to constrain or facilitary policy."

Ruzic, Neil P.

Why are we in space? Air University review, v. 31, Nov.-Dec. 1979: 34-48.

"Even after a fledgling 20 years of space activities, we can point to significant accomplishments by considering what the world would be like if we were not in space." The article considers some benefits of space exploration: communications, weather forecasting, energy, etc.

Sagan, Carl.

Cosmos. New York, Random House, c1980. 365 p.

Based on . . . 13-part television series.

Why we need to understand science. Parade magazine, Washington post, Sept. 10, 1989: 6, 8-10.

Points out that while we live in a society dependent on science and technology, most people know very little about science and technology. Warns that "ignorance of science threatens our economic well-being, national security and the democratic process."

Satellite technology and world food security; report prepared for the the Select Committee on Hunger, U.S. House of Representatives, by the Congressional Research Service, Library of Congress. Washington, G.P.O., 1989. 53 p.

"The report covers the activities of the United States, foreign nations and international agencies concerned with agricultural assessment, monitoring of the environment and natural resources, and with development and applications of satellite monitoring systems. A separate section describes in detail the U.S. and international satellite systems currently in operation and planned for the future. It concludes with a discussion of policy issues concerning space monitoring applications to agriculture and food security."

Schefter, Jim.

It's time to stop the space retreat. Popular science, v. 221, Oct. 1982: 32, 34, 38, 40-43, 45.

Points to the economic, technological, and defense benefits of a comprehensive space program.

Schichtle, Cass.

The National Space Program: from the fifties into the eighties. Washington, National Defense University, for sales by the Supt. of Docs., G.P.O., 1983. 122 p. (National security affairs monograph series 83-6) LRS83-13657

Contents.--Policy development retrospective.--The evolution of the US space organization.

Schmitt, Harrison.

Civilization in space: the chronicles plan. Capitol studies, v. 6, fall 1978: 5-10.

Senator and former astronaut addresses the problems facing the United States in attempting to formulate a successful space policy.

Schnapf, Lawrence.

Explorations in space law: an examination of the legal issues raised by geostationary, remote sensing, and direct broadcasting satellites. New York Law School law review, v. 29, no. 4, 1985: 687-748.

This note reviews the five treaties which to date comprise the law of outer space and examines three areas in which there are gaps in the law. Discusses proposals under consideration to regulate satellite operations and recommends solutions.

Schwarz, Michiel, ed. Stares, Paul, ed.

Space--past, present, and future. Futures, v. 14, Oct. 1982: whole issue.

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International Space Policy for the 1990s and beyond. [Washington, The Administration] 1987. 46 p.

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Co-ordination of outer space activities within the United Nations system: programmes of work for 1980 and 1981 and future years; report. New York, 1979. 25, 2 p. (United Nations. Document A/AC.105/242)

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Prelude to the space age; the rocket societies: 1924-1940. Washington, Smithsonian Institution Press, 1983. 207 p.
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Wolfe, Tom.
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Space station: policy, planning and utilization; proceedings of the AIAA/NASA symposium. Edited by Mireille Gerard and Pamela W. Edwards. New York, AIAA, c1983. 216 p. (AIAA aerospace assessment series; v. 10)

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The payoff in outer space. Space world, v. 0-6-174, June 1978: 27-29.

Argues for the advantages of the exploration of outer space by refering to spinoffs such as navigational satellites, the potential for fostering world unity, the possibility of cheap solar energy, and new technological advances.

Why we must explore the moon. Science digest, v. 66, Oct. 1969: 8-17.

"A well-known scientist and science writer spells out the reasons--practical as well as esoteric--why we have to continue with our space program, regardless of the costs."

Baker, James D.

Mission to planet Earth. Aerospace America, v. 26, July 1988: 44-46.

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Baker, James D. Wiison, W. Stanley.

Spaceborne observations in support of earth science, by James D. Baker and W. Stanley Wilson. Oceanus, v. 29, winter 1986-1984: 76-85.

Contends that earth resources satellites have stimulated the realization that environmental change is a global process.

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A close look at Halley's Comet. Scientific American, v. 259, Sept. 1988: 96-103.

Describes images and data acquired from the space probes that flew past Halley's Comet. Especially focuses on results obtained from Giotto, the European probe.

Begley, Sharon. Hager, Mary.

A fantastic voyage to Neptune. Newsweek, v. 114, Sept. 4, 1989: 50-56.

"Twelve years after its interplanetary odyssey began, the unmanned space probe Voyager 2 arrived at Neptune, the planet currently farthest from the sun. It found a turbulent place of storms as big as Earth and careering particles forming rings as dark as midnight. For all its spectacle, though, the blue planet was nearly upstaged by its moon Triton, a mottled pink-as-blue world of craters, smooth plains and vast ice basins.

Bell, M. W. Jack.

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Profiles the next generation space transportation system and surmises that it may utilize "fully reusable, lightweight flight elements and highly reliable, longlife system hardware and extensively employ built-in test equipment."

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Voyager: science at Saturn. Astronomy, v. 9, Feb. 1981: 7, 9-11, 15-16, 18, 20-22.

Discusses the data generated by the Voyager reconnaissance of Saturn.

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Space science: what's wrong at NASA. Issues in science and technology, v. 5, winter 1988-89: 67-73.

Using the Hubble Space Telescope as an example, the author points out what is wrong with how NASA conducts space science. The problems are: "overreliance on the space shuttle, a predilection for big projects, and poor management."

Borrowman, Gerald L.

Operation Morninglight. Spaceflight, v. 21, July 1979: 302-307.

Describes the problems presented when the Soviet Satellite Cosmos 954 fell into Canada's Northwest Territories. Believes this to be an object lesson for other unscheduled re-entries of Earth-orbiting spacecraft.

Brodsky, Robert F. Morais, Bernard G.

Space 2020: the technology, the missions likely 20-40 years from now. Aeronautics & astronautics, v. 20, May 1982: 54-73.

Sets out what could happen in space in the next 40 years. Foresees continued development of the military uses of space, further exploration of the solar system and manufacturing in space.

Bulloch, Chris.

Search and rescue by satellite: slow steps towards an operational system. Interavia, v. 42, Mar. 1987: 275-277.

Discusses the planned search-and-rescue satellite system.

Spaceflight to 2000: Interavia looks forward from the present. Interavia, v. 38, Nov. 1983: 1185-1192.

"Looks at some of the roles likely to be played by spacecraft out to the end of this century, and the technologies that may be employed to fulfil[l] these roles. It also looks at some of the economic and political factors influencing the growth of space activities."

Burbidge, E. Margaret.

Adventure into space. Science, v. 221, July 29, 1983: 421-427.

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Burke, Bernard F.

Radio telescopes bigger than the Earth. Astronautics & aeronautics, v. 20, Oct. 1982: 44-52.

"Very long baseline interferometry (VLBI) already allows radio astronomers to view the universe with angular resolution a thousand times better than the 200-inch telescope's, and putting radio antennas in space can extend the power of the method almost without limit."

Chang, Thelma.

On the road to Io. Air & space, v. 3, Dec. 1988-Jan. 1989: 71-75.

Describes the voyage of the space probe Galileo, which will photograph and provide samples of Jupiter's atmosphere and observe Io's volcanic activity.

Clark, John.

NEO space--the case for the space program. Space world, v. H-12-96, Dec. 1971: 27-30.

Clark, Phillip S.

The Soviet Venera programme. Journal of the British Interplanetary Society, v. 38, Feb. 1985: 74-93.

Reviews the Soviet space missions towards Venus since 1961. Successful probes since 1975 have resulted in four spacecraft being placed into orbits around Venus and six descent craft making soft landings on the surface.

Soviet spacecraft recoveries. Journal of the British Interplanetary Society, v. 36, Apr. 1983: 186-191.

Clayton, D. C. Truss, P.

The Giotto spacecraft configuration and its achievement. Journal of the British Interplanetary Society, v. 38, May 1985: 222-230.

"The considerations leading to the final design of the European Space Agency Giotto Halley's comet probe are discussed, including scientific payload, launch vehicle, thermal control, and spacecraft balance requirements."

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Onward the space station. National journal, v. 18, Nov. 15, 1986: 2760-2763.
"The Challenger tragedy hasn't derailed NASA's plans to man a space station by the 1990s. But logistics are being rethought, and foreign partners are seeking larger roles."

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Hubble telescope poised to probe secrets of universe. Aviation week & space technology, v. 132, Mar. 26, 1990: 38-39.
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David, Leonard W.
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"Reviews the reasons for humans voyaging to the Red Planet."

DeNevi, Don.
To the edges of the universe: space exploration in the 20th century. Millbrae, Calif. Celestial Arts, c1978. 213 p.

Desaussure, Hamilton.
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This article examines the legal problems that may arise over permanently manned space stations.

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Intelligent life in space. New York, Macmillan, 1962.

Draper, Ronald F.
Affordable solar system exploration. Aerospace America, v. 24, Oct. 1986: 28-31.
"A family of spacecraft under design will fly formation with a comet and spike it with a probe, sail by asteroids, and cruise the outer planets at reasonable cost."

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Towards a lunar base programme. Space policy, v. 1, Feb. 1985: 49-61.
"This article examines a manned lunar base in terms of three distinct functions: the scientific investigation of the Moon and its environment; development of the capability to use lunar resources for beneficial purposes throughout the Earth-Moon system; and conduct of R&D leading to a self-sufficient and self-supporting manned lunar base."

Dyson, Freeman.
Human consequences of the exploration of space. Bulletin of the atomic scientists, v. 25, Sept. 1969: 8-13.
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Interview: Krafft Ehricke. Omni, v. 3, Sept. 1981: 87-88, 90-91, 124.
"The V-2 colleague of Wernher von Braun and creator of mighty rockets now turns his technical clairvoyance toward humans in outer space."

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Shuttle for the 21st century. Aerospace America, v. 22, Apr. 1984: 82-84, 86.
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Breakout into space: mission for a generation. New York, Morrow, 1990. 213 p.

Exley, Elwood, Jr.
The new astronaut breed. Space world, v. R-11-215, Nov. 1981: 18-21.

Profiles the new scientist-astronauts being trained by NASA to conduct experiments aboard the space shuttle.

Exploration initiative: a long-range, continuing commitment. Washington, U.S. National Aeronautics and Space Administration, Office of Exploration, 1990. 54 l.

Outlines possible space exploration projects including missions to Mars and the moon.

Exploring the living universe: a strategy for space life sciences. [Washington] U.S. National Aeronautics and Space Administration, Life Sciences Strategic Planning Study Committee, 1988. 217 p.

Recommends that NASA expand its life sciences research program to support the manned space station and the efforts to study biological process and life in the universe.

Extra-terrestrial communities. Spaceflight, v. 18, Apr. 1976: 130-134.

Summarizes the work of the NASA/Ames-Stanford ASEE Study on Space Colonization, that resulted in a design for a complete space colonization system including launch vehicles, processing plants self-maintaining and Earth-like habitat for 10,000 people.

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Electric propulsion of spacecraft. Journal of the British Interplanetary Society, v. 35, Apr. 1982: 156-166.

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A programme for interstellar exploration. Journal of British Interplanetary Society, v. 29, Oct. 1976: 611-632.

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The improbability of space colonies. Space world, v. 0-6-174, June 1978: 10-15.

Summarizes the optimistic approach toward space colonies taken by O'Neill in his "The High Frontier." Discusses the necessity for minute regimentation of populations in space and the question of space industry profitability. Concludes that the tremendous costs will preclude space colonization.

Freitag, Robert F.
Man's future in space. Spaceflight, v. 17, Mar. 1975: 82-87.

Outlook for man's future in space for 1980-2000.

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The case for interstellar probes. Journal of the British Interplanetary Society, v. 36, Nov. 1983: 490-495.

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Exploration of the asteroids, by James R. French, Jr. and Neal D. Hulkower. Journal of the British Interplanetary Society, v. 35, Apr. 1982: 167-171.

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Mars sample-return options, by J. R. French, H. N. Norton; and G. A. Klein. Aerospace America, v. 23, Nov. 1985: 50-56, 58.

Accompanying article: Designing a Mars Surface Rover, by Carl Ruoff Brian Wilcox and Gail Kelin, p. 54-58.

"Return of a carefully selected set of sample materials from the surface of Mars will be the most challenging and demanding unmanned planetary science mission of this century." States that delay of this mission into the 1990's, while disappointing to the scientists involved, offers some advantages in increased technological capability."

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Starsailing: solar sails and interstellar travel. New York, Wiley, c1988. 146 p. (Wiley science editions)

Friedrich, Otto.

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Describes the success of the Soviet space program. Concludes that the Soviet Union has surpassed the United States in space exploration and is likely to dominate space by the 21st century.

Froehlich, Walter.

Man in space. Washington, National Aeronautics and Space Administration [For sale by the Supt. of Docs., G.P.O., 1971] 21 p. (Space in the seventies)

Space station: the next logical step. Washington, National Aeronautics and Space Administration [For sale by the Supt. of Docs., G.P.O, 1984?] 51 p.

From Disaster to Discovery. New York, CBS News, 1988. 15 p. (Transcript no. 11)

Transcript of a program aired on April 21, 1988 on the U.S. space shuttle program, the risks of manned spaceflight, and the testing of the next shuttle Discovery.

Froning, David.

Reaching the further stars. Spaceflight, v. 25, Dec. 1983: 446-450.

"Rapid transit to distant stars would involve starship acceleration to light-velocity and disappearance from human sight. Almost immediately, it would reappear billions of kilometres away in close proximity to its target star, but during those moments of disappearance, the starship would have 'jumped' over so-called space and time."

Furniss, Tim.

Countdown to co-operation. Flight international, v. 132, Dec. 5, 1987: 30-33.

Describes the Soviet Union's future space exploration program and its efforts to encourage international participation in each project, including the Mars mission.

Satellites on a string. Flight international, v. 134, July 16, 1988: 35-37.

Describes the workings and applications of tethered satellites which will be dragged through space by the space shuttle.

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The space telescope. New York, Gallery Books, 1987. 143 p.

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The Einstein Observatory: new perspectives in astronomy. Science, v. 209, Aug. 22, 1980: 865-876.

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Space trek: the endless migration. Harrisonburg, Pa., Stackpole Books, c1978. 223 p.

Gold, Thomas.
Machines, not men in space. New York times magazine, Aug. 22, 1971: 16-17, 20, 22, 24, 28, 30.

An astrophysicist tells why he thinks that machines instead of men should be used in exploring space.

Goldberg, Jeff.
Lunar reflections. Omni, v. 11, July 1989: 35-36, 38, 40, 80, 82-88.

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The search for life in the universe. Menlo Park, Calif., Benjamin/Cummings Pub. Co., c1980. 434 p.

Gordon, Theodore J.
A futurist's view of space. Futures research quarterly, v. 1, fall 1985: 19-27.

Gore, Rick.
Voyager 1 at Saturn: riddles of the rings. National geographic magazine, v. 160, July 1981: 3-31.

Greeley, Ronald, ed. Carr, Michael H., ed.
A geological basis for the exploration of the planets. Washington, National Aeronautics and Space Administration, Scientific and Technical Information Office; for sale by NTIS, 1976. 109 p.

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Moving from dream to reality. Environment, v. 25, Nov. 1983: 7-13, 33-40.

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Grimes, Vincent.
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Nuclear slingshot: project Galileo sparks outcry. Nation, v. 249, Oct. 2, 1989: 336.

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The path to space shuttle: the evolution of lifting reentry technology. Journal of the British Interplanetary Society, v. 36, 1983: 523-541.

Recounts the development of the design for the Space Shuttle. "The actual evolutionary path to the first winged reentry spacecraft is marked by numerous false starts, roads not taken, innovative decision-making, and carefully thought-out analysis of just what such spacecraft should be expected to do."

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Freedom of passage on the high seas of space. Atlantic Community quarterly, v. 16, fall 1978: 345-357.

"Preserving the freedom to operate on the high seas of space is essential to the future well-being of all nations. Securing space for free travel and commerce to the benefit of all, ideally, should be the aim of all the nations of the world."

Harding, Peter X.

Parallels in isolation: managing space problems in Antarctica. Fletcher forum, v. 5, summer 1981: 222-242.

"As more time is spent in the exploration and inhabitation of space, periods of isolation will grow longer, accompanied by unique forms of stress for individuals functioning in an artificial environment. In this article, Mr. Harding, once an expedition leader in Antarctica, discuss the similarities found in the stresses imposed on individuals working in Antarctica and space and the methods for managing problems encountered in isolation."

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Henbest, Nigel.

First light on starbirth. New scientist, v. 115, Aug. 27, 1987: 46-49.

The Infrared Astronomical Satellite (IRAS), launched in January 1983, has been used to observe protostars and has helped astronomers to deduce how stars are formed.

Heppenheimer, T. A.

Colonies in space. Harrisburg, Pa., Stackpole Books, c1977. 244 p.

This work was reprinted in 1978 by Warner Books.

The space station nobody wants. Reason, v. 19, Feb. 1988: 22-28.

Author contends that the U.S. space station project was approved on the basis of President Reagan's personal enthusiasm for space. Maintains NASA is pursuing a project which may never be launched, while ignoring the problem of developing reliable launch vehicles.

Holocaust in the sky. Discover, v. 7, Apr. 1986: 38, 40-51, 54-68.
Contents.--What destroyed the Challenger? by Wayne Biddle.--The new American dream, by Walter A. McDougall.

Hubbard, Earl.
The need for new worlds. Futurist, v. 3, Oct. 1969: 117-118.
"A Space Age philosopher proposes that man should move out from the earth and colonize the universe. He believes that in exploring and developing new worlds, man will find the means of uniting the world, dealing with problems on earth, and opening up a future of infinite possibility for mankind."

Hubble Telescope deployment set for record shuttle altitude. Aviation week & space technology, v. 132, Mar. 26, 1990: 40-42, 44-45.
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The direct investigation of comets by space probes. Journal of the British Interplanetary Society, v. 30, Jan. 1977: 3-14.
"This paper discusses the selection criteria applied to possible cometary candidates, the types of space probe missions considered, the major scientific objectives in this first step towards direct visit to a comet and a typical experimental payload."

Mission to the comets. New scientist, v. 85, Jan. 10, 1980: 66-69.
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Missions to minor bodies. Space flight, v. 30, July 1988: 296-297, 299.
Proposes three stages of exploration to minor astronautical bodies, such as comets and asteroids, to acquire adequate information and samples for scientific study.

Human uses of outer space. Society, v. 21, Jan.-Feb. 1984: 8-44.
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International solar-terrestrial physics program: a plan for the core spaceflight missions. [Washington] U.S. National Aeronautics and Space Administration [1985] 21 p.
"This brochure has been prepared by NASA on behalf of the European Space Agency (ESA), the Institute of Space and Astronatical Science (Japan) (ISAS), and the U.S. National Aeronautics and Space Administration (NASA) to describe the scope of the science problems to be investigated and the mission plan for the core International Solar-Terrestrial Physics (ISTP) Program."

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"Proceedings of the Conference on Interstellar Migration held at Los Alamos in May 1983."

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Onward to Mars. Time, v. 132, July 18, 1988: 46-53.
Describes the renewed interest in exploring Mars by the U.S. and U.S.S.R.

Jastrow, Robert.
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Johnson, J. T.
Silver bagel and flying carrot. Popular science, v. 223, Oct. 1983: 110, 112-113.

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Joyce, Christopher.
Space travel is no joyride. Psychology today, v. 18, May 1984: 30-32, 34-37.

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Voyager to Uranus and Neptune. Astronomy, v. 11, Apr. 1983: 7-11.

Describes how scientists made use of Jupiter's gravitational field to send Voyager 2 on to Saturn, Neptune and Uranus.

Kantrowitz, Arthur.
The relevance of space. Bulletin of the atomic scientists, v. 27, Apr. 1971: 32-33.

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Kerwin, Joseph.
House calls in space: a doctor-astronaut's view. Space world, v. N-3-159, Mar. 1977: 26-29.

Physician-astronaut Kerwin, describes the medical effects of space flight as noted during his 28 day Skylab mission.

Kidger, Neville.
The Interkosmos programme 1967-1980: a brief overview. Spaceflight, v. 23, June 6, 1981: 161-165.

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Lebeau, Andre.
The astronaut and the robot: short- and long-term scenarios for space technology. Space policy, v. 3, Aug. 1987: 207-220.

"Outlines the growing gap between the immediate needs of organizations which launch satellites and the more uncertain ambitions of the 'conquerors' of space. Suggests that an attempt should be made to reconcile immediate military and industrial needs with the human desire to overcome the 'Icarus complex' in the long-term future."

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Lewis, Richard S.
Appointment on the moon: the full story of Americans in space from Explorer One to Lunar Landing and Beyond. New York, Viking Press, 1968. 434 p.

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Life among the stars. Mosaic, v. 8, Mar.-Apr. 1977: 15-21.
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Proceedings of the Conference on Life in the Universe, held at NASA Ames Research Center, June 19-20, 1979.

Lindaman, Edward B.
Space, a new direction for mankind. New York, Harper & Row [1969] 158 p.

Loftus, J. P.
An historical overview of NASA manned spacecraft and their crew stations. Journal of the British Interplanetary Society, v. 38, Aug. 1985: 354-370.
Summarizes "the crew station characteristics of the Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz and Space Shuttle spacecraft and the design strategies that dictated those characteristics."

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The space shuttle program: a policy failure? Science, v. 232, May 30, 1986: 1099-1105.
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A reflective review of man's venture into space. Aviation, space, and environmental medicine, v. 50, Jan. 1979: 63-67.
Astronaut from the Gemini Program describes his experiences in the program, the benefits derived from space activity, and presents a look into the future of space exploration.

Lunan, Duncan.
Man and the planets: the resources of the solar system. Bath, Ashgrove Press, 198[illegible] 306 p.

Mack, Pamela Etter.
Viewing the earth: the social construction of the Landsat satellite system. Cambridge, Mass., MIT Press, 1990. (Inside technology)
This work will be available later in 1990.

Mallove, Eugene F.
The quickening universe: cosmic evolution and human destiny. New York, St. Martin's Press, 1987. 268 p.

Renaissance in the search for galactic civilizations. Technology review, v. 87, Jan. 1984: 48, 51-54.
"After years of dreams, debates, and ingenious but sporadic efforts, new technology is moving the search for extraterrestrial intelligence a huge step forward. We are ever closer to answering that age-old question: are we alone in the universe?"

The starflight handbook: a pioneer's guide to interstellar travel, by Eugene Mallove and Gregory L. Matloff. New York, Wiley, 1989. 274 p.
"This guide to spaceflight puts the heavy . . . technical and mathematical explanations of the how and why of rocket propulsion in sidebars where they won't scare off those who are happier with an imaginative and readable explanation. Just what is needed before setting out to explore the universe."

Man in space. NATO's fifteen nations, v. 27, Apr.-May 1982: 18-20, 22-25, 27-28, 32, 34-39, 42-45, 48, 50, 53.

Partial contents.--For peace or for war? by H. Curien.--Observation in space--past, present and future, by J. Arnbak.--Communications space systems, by I. Mason-Smith.--Outer space for man: a Soviet vision, by G. Petrov.--Soviet space probes land on Venus, by Y. Zaitsev.

Manned Space Capsules. Journal of the British Interplanetary Society, v. 42, Feb. 1989: whole issue (96 p.)

Contents.--Multi-role capsule--an introduction, by C. M. Hempsell.--Rationale and requirements for the multi-role capsule, by C. M. Hempsell.--Multi-role capsule system description, by C. M. Hempsell and R. J. Hannigan.--Multi-role capsule operations, by R. J. Hannigan.--The re-entry environment of the multi-role capsule. I. Walters and C. M. Hempsell.--Multi-role capsule: programme and costs, by C. M. Hempsell and R. C. Parkinson.

Man's voyage through the solar system. Economist, v. 287, Apr. 9, 1983: 83-84, 86-88.

Describes the formation of the solar system and future possibilities for space exploration.

Maran, Stephen P. Boggess, Albert, III.

Two satellites in search of X-rays. Natural history, v. 89, Mar. 1980: 78, 82-85.

Contends that the X-ray observations of the two high energy astronomy observatory satellites are not sensitive enough to provide a conclusive answer as to whether the universe is open or closed.

Ultraviolet astronomy enters the eighties. Physics today, v. 33, Sept. 1980: 40-46.

"A decade of observations by Earth-orbiting satellites has led to the discovery of compact, hot components in many stellar systems and extended coronas surrounding our Galaxy and others."

Mars: special report. Discover, v. 5, Sept. 1984: 12-17, 20-21, 24-26.

Contents.--Mars or bust, by A. Chaikin.--Visions from Viking, by S. Brownlee.--The mystique of Mars, by D. Overbye.--The case for Mars, by C. Sagan.

Marsh, Peter.

Scientists gain a foothold in space. New scientist, v. 99, Sept. 22, 1983: 874-879.

Notes that the scientific community is divided over the probable benefits of Spacelab.

Martin, Franklin D. Finn, Terence T.

Space station: leadership for the future. Washington, National Aeronautics and Space Administration, 1987. 8 p.

"No longer limited to occasional spectaculars, space has become an essential, almost commonplace dimension of national life. Among other things, space today is an arena of competition with our allies and our adversaries. It is a place of business, where private companies can and do profit. It is a field of research, for developing technology and conducting science. It is also an avenue of cooperation with our allies, demonstrating the peaceful use of space for the benefit of all.

The Space Station will play a critical role in each of these endeavors. A unique and versatile concept, the Space Station will shape what we do in space and how we do it. And by doing so, it will be the centerpiece of our nation's future in space.

The Space Station will be unique because it will provide the United States with a permanently manned presence in space."

Martin, Franklin D. Ladwig, Alan.

Gateway to the solar system. World & I, v. 4, July 1989: 324-329.

Contends that a return to the moon could prove to be an excellent stepping-stone to further exploration of our solar system.

Martin, Tony, and others.

The Fermi Paradox: a forum for discussion. Journal of the British Interplanetary Society, v. 32, Nov. 1979: 424-434.

Report views presented at the Second British Interplanetary Society Conference on Interstellar Travel and Communication on the Fermi Paradox: "if life is common in the Galaxy, and the development of intelligent, technical civilisation is not unique to Earth, then why do we see no signs of this life."

Mathews, J. M., ed.

TRW space log, 1980. Redondo Beach, Calif., TRW Defense and Space Systems Group, 1981. 99 p.

Provides information on new satellites to be launched and also contains a compilation of space probes and satellites launched between 1957 and 1980.

McCurdy, Howard E.

The space station decision: incremental politics and technical choice. Baltimore, Johns Hopkins University Press, c1990.

This work will be available later in 1990.

McDonough, Thomas R.

Space, the next twenty-five years. New York, Wiley, 1987. 237 p. (Wiley Science editions)

McLaughlin, Bill.

Halley's comet--messenger from space. Spaceflight, v. 23, Aug.-Sept. 1981: 212-213.

Suggests the importance of a mission to Halley's comet and notes that "Halley is particularly important because it is still a relatively young, active comet with a well-known history and orbit."

McRedmond, Dennis P.

Is space worth it? Space world, v. 1-3-99, Mar. 1972: 20-21.

"The exploration of outer space has already resulted in a wealth of knowledge greatly beneficial to our nation. New technologies, new products, new systems, and new technigues have been developed with beneficial offshoots in many fields."

Michaud, Michael A. G.

An extraterrestrial ethos. America, v. 139, Nov. 11, 1978: 300-331.

"Even with man's present technology, permanent space stations and the development of resources from distant planets are possible. A new ethical sense must stretch beyond earthbound experience."

Molton, Peter M.

On the likelihood of a human interstellar civilization. Journal of the British Interplanetary Society v. 31, June 1978: 203-208.

Examines the arguments for and against the exploration of interstellar space. Concludes that governments will probably not make resources available for such a long term project, mainly for political reasons.

The Moon & space. Science digest, v. 66, Oct. 1969: 7-29.

Contents.--Why we must explore the moon, by I. Asimov.--They find moonscapes on the earth, by B. Frisch.--Moon madness: does it really exist?, by J. Cottrell.

Moore, Aidan M. G.

The coup against entropy. Spaceflight, v. 18, Apr. 1976: 126-129.

Suggests that the complex molecular structures that emerged on Earth 3,000 million years ago helped create and perpetuate the Earth's unique atmosphere. Examines man's fitness for space travel and argues that information overload and environmental threats will cause the extinction of man unless he establishes himself on other worlds.

Moore, Patrick.

Space. [1st ed. in the U.S.A.] Garden City, N.Y, Published for the American Museum of Natural History by Natural History Press, 1969 [c1968] 216 p.

Morrison, David C.

Beyond the blue yonder. National journal, v. 20, Mar. 26, 1988: 798-802

A program for planetary exploration, by David Morrison and Noel W. Hinners. Science, v. 220, May 6, 1983: 561-567.

"On the basis of a two-year study, the NASA Solar System Exploration Committee recommends a core program of planetary missions through the year 2000. By incorporating a number of cost-saving measures, an exciting program of planetary exploration can be achieved within a highly constrained NASA budget."

Mueller, George.

Antimatter & distant space flight. Spaceflight, v. 25, May 1983: 202-207.

Multinational European efforts in space. Aviation week & space technology, v. 116, Mar. 8, 1982: 88-89, 91.

Murray, Bruce.

Civilian space: in search of Presidential goals. Issues in science and technology, v. 2, spring 1986: 25-37.

"Argues that manned space flight can only be justified when the goal is human adventure and exploration. Unmanned flight, Murray says, is a much more cost-effective way to advance science and carry out most other practical activities in space, especially in an era when the capabilities of robots and computers are growing rapidly."

Journey into space: the first three decades of space exploration. 1st ed. New York, Norton, c1989. 381 p.

NASA Advisory Council. Solar System Exploration Committee.

A core program: mission operations: planetary exploration through year 2000: a report. Washington, NASA, For sale by the Supt. of Docs., G.P.O, 1986. 55 p.

Planetary exploration through year 2000: a Core program: part one of a report, by the Solar System Exploration Committee of the NASA Advisory Council. Washington, NASA, For sale by the Supt. of Docs., G.P.O, 1983. 167 p.

Planetary exploration through year 2000: an augmented program: part two of a report. Washington, NASA, For sale by the Supt. of Docs., G.P.O., 1986. 239 p.

NASA's Solar Maximum Mission: a look at a new sun. Prepared by the SMM Principal Investigator Teams. Edited by Joseph B. Gurman. [Washington] National Aeronautics and Space Administration, 1987. 34 p.

Describes the findings of the Solar Maximum Mission (SMM) spacecraft, launched in February 1981 and repaired in April 1984, regarding solar flare, the sun as a star, and the solar atmosphere.

National Research Council. Committee on Human Exploration of Space.

Human exploration of space; a review of NASA's 90-day study and alternatives. Washington, National Academy Press, 1990. 63 p.

"In examining the NASA *Report of the 90-Day Study on Human Exploration of the Moon and Mars* and alternative concepts, the committee concluded that the appropriate framework in which to consider alternative approaches to meeting the President's initiative has at least four components. The committee's major findings and conclusions . . . [are] presented in that framework."

Neugebauer, Marcia.

Space missions to comets. Physics today, v. 38, Nov. 1985: 38, 40-44.

"Five spacecraft now heading toward an ambitious March 1986 encounter with comet Halley mark the beginning of a new era in cometary research, which promises to modify our understanding of the evolution of the solar system."

Newburn, Ray L., Jr., and others.

Why go to the outer planets? Astronautics & aeronautics, v. 8, Sept. 1970: 39-44.

Newell, Homer Edward.
Beyond the atmosphere: early years of space science. Washington, Scientific and Technical Information Branch, National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1980. 497 p. (The NASA history series. NASA SP; 4211)

The Next giant leap in space: a agenda for international cooperation; final report. New York, United Nations Association of the United States of America, c1986. 70 p.

"This report represents the consensus of a broad array of Americans on how best to work with other countries to encourage the peaceful exploration and development of" outer space.

Nicholson, Iain.
The road to the stars. New York, Morrow, 1978. 224 p.

Oberg, Alcestis R.
Spacefarers of the '80s and '90s: the next thousand people in space. New York, Columbia University Press, 1985. 238 p.

"Astronauts are a changing breed, ranging from the test pilots of the 1960s to the scientists, teachers, politicians, and journalists of the 1980s and 1990s. This book tells what it will take and what it will be like to be an astronaut in the future.

Oberg, James E.
Mission to Mars: plans and concepts for the first manned landing. New York, New American Library [1983] c1982. 221 p.

New earths: restructuring Earth and other planets. New York, New American Library [1983] c1981. 283 p.

The new race for space: the U.S. and Russia leap to the challenge for unlimited rewards. Foreword by Ben Bova. Harrisburg, Pa., Stackpole Books, c1984. 210 p.

Salyut. Space world, v. P-4-184, Apr. 1979: 4-34.

Special issue on the Russian Salyut manned space program. Articles on the history of the program, the international cooperative aspects, military Salyuts, and medical-biological aspects of the program.

Tracking the booster gap. Defense electronics, v. 20, May 1988: 83-89, 86, 88, 90.

Examines the Soviet Union's space launch capability. Discusses the early failure of Soviet boosters and speculates on the reasons for the Soviet's current surplus launch capacity. Outlines the prevalent orbit pattern of Soviet space missions. Concludes with a brief discussion of the development of Soviet superboosters and winged spacecraft.

Uncovering Soviet disasters: exploring the limits of glasnost. New York, Random House, c1988. 317 p.

Ogilvie, K. W. VonRosenving, T. Durney, A. C.
International Sun-Earth Explorer: a three-spacecraft program. Science, v. 198, Oct. 14, 1977: 131-138.

"The International Sun-Earth Explorer is a three-sapcecraft program of the National Aeronautics and Space Administration and the European Space Agency aimed at securing a more quantitative knowledge of the structure and stability of magnetosphere."

O'Leary, Brian.
Exploring inner and outer space: a scientist's perspective on personal and planetary transformation. Berkeley, Calif., NorthAtlantic Books, c1989.

This work will be available later in 1990.

The making of an ex-astronaut. Boston, Houghton Mifflin, 1970. 243 p.

O'Neill, Gerard K.
The high frontier: human colonies in space. New York, Morrow, 1977, c1976. 288 p.

This work was reprinted in 1982 by Anchor books.

Orbit on demand. Aerospace America, v. 23, Feb. 1985: 46-48, 50-61

Contents.--Orbit on demand: in this century if pushed, by J. Martin.--Orbit on demand: will cost determine best design?, by I. MacConochie.--Orbit-on-demand vehicles: mission possible, but one-day turnaround?, by T. Talay.--Orbit on demand: structural analysis finds vertical launchers weigh less, by A. Taylor.

Other worlds from earth: the future of planetary astronomy: a report of the Planetary Astronomy Committee of the Solar System Exploration Division. Washington, D.C., National Aeronautics and Space Administration, For sale by the Supt. of Docs., U.S. G.P.O, 1989. 97 p.

Outward to the beginning: the CRAF and cassini missions of the Mariner Mark II program. Washington, U.S. National Aeronautics and Space Administration, 1988. 16 p.

Profiles the Rendezvous Asteroid Fly by (CRAF) and Cassini (the Saturn orbiter/Titan Probe), part of the Mariner Mark II program. They will explore the primitive bodies of the solar system, comets and asteroids and the Saturnian system including its rings and moons.

Overbye, Dennis.
Man in space: special report, by Dennis Overbye and Natalie Agnier. Discover, v. 5, Apr. 1984: 13-18, 20-21, 24-27, 30-31.

Parkinson, R. C.
A manned Mars mission for 1995. Journal of the British Interplanetary Society, v. 34, Oct. 1981: 411-424.

"Examines a mission using the 1995 opportunity for an Earth-Mars-Venus (swingby)-Earth round trip with three vehicles (two Orbiters and one Lander) and a crew of five leaving Earth-orbit in November 1994. The vehicles would use a Heavy Boost Stage for depature from Earth orbit, a smaller stage for entry into orbit about Mars and a near identical stage for the return journey from Mars to Earth."

Pearson, Jerome.
Ride an elevator into space. New scientist, v. 121, Jan. 14, 1989: 58-61.

"Rockets are an expensive, dangerous and inefficient way of going into space. An alternative is to take an elevator to orbit. Some of the principles that apply to space elevators can also be exploited for tethers linking spacecraft together."

Peebles, Curtis.
The origins of the U.S. space shuttle. Spaceflight, v. 21, Nov. 1979: 435-442; Dec. 1979: 487-492.

Presents the various forerunners in the development of the U.S. space shuttle.

Pesavento, Peter.
Soviet spaceflight comes of age. New scientist, v. 110, Apr. 10, 1986: 44-47.

Reviews a quarter of a century of Soviet space flight.

Puttkamer, Jesco von.
Roles and needs of man in space. Journal of the British Interplanetary Society, v. 36, Aug. 1983: 351-356.

Radiation hazards in space. Aerospace America, v. 25, Oct. 1987: 38-41.

Upcoming manned missions to the Moon and Mars, and the space station will require man to remain in space for years at a time. Describes what devices are known that will provide protection against galactic cosmic rays, solar flare particles, and trapped Van Allen radiation. Also describes how radiation dose limits are determined and measured.

Regimes for the ocean, outer space, and weather by Seyom Brown and others. Washington, Brookings Institution, c1977. 257 p.

Report of the 90-day study on human exploration of the Moon and Mars. Washington, National Aeronautics and Space Administration, 1989. 139 p.

"The Human Exploration Initiative provides a framework within which various elements of and approaches to human exploration of the Moon and Mars can be examined . . . . Five reference approaches were analyzed, each of which is characterized by a particular emphasis: (1) balance and speed; (2) the earliest possible landing on Mars; (3) reduced logistics from Earth; (4) schedule adapted to Space Station Freedom; and (5) reduced scale."

Ressmeyer, Roger.

Space places. San Francisco, Collins Publishers, 1990.

This work will be available later in 1990.

Rice, Berkeley.

Space-lab encounters. Psychology today, v. 17, June 1983: 50-59.

Behavioral scientists at Johns Hopkins study the psychological and physiological effects of prolonged confinement on two-and three-person microsocieties. "Their goal is to develop behavioral guidelines for the most productive individual and group performance, with the least social friction, on future space and underwater missions."

Rickert, Russell K.

Astronomy and space exploration. [Reading, Mass., Addison-Wesley Pub. Co., 1974] 342 p. (Addison-Wesley series in physics)

Ride, Sally K.

Leadership and America's future in space; a report to the administrator of the National Aeronautics and Space Administration. Washington, The Administration, 1987. 63 p.

"In response to growing concern over the posture and long-term direction of the U.S. civilian space program, NASA Administrator Dr. James Fletcher formed a task group to define potential U.S. space initiatives, and to evaluate them in light of the current space program and the nation's desire to regain and retain space leadership. Exploration of the Solar System, 3) Outpost on the Moon, and 4) Humans to Mars, the task group recommended exploration of the Moon and human exploration of Mars.

Ridpath, Ian.

Discovering space. Tring, Shire Publications, 1972. 64 p.

Robinson, George S.

Who owns the moon? Foreign Service journal, v. 58, July-Aug. 1981: 22-25.

"In the evolution of space law, too many nations and people believed in an effective and successful ambience of cooperation for peaceful purposes in near- and deep-space activities. It distracted some of the decision-makers from proper considerations of the true military, economic, political, and ideological motivations of the primary space-law negotiators."

Rodionov, B.

Earth explored from space. Space world, v. 1-3-99, Mar. 1972: 16-17.

Rolan, Robert G.

Must we choose between men in space and mankind on Earth. Bioscience, v. 20, July 15, 1970: 797-806.

"This paper is an attempt, to determine whether the goals of manned space flight and environmental improvement on Earth are really competitive and mutually exclusive or are, in fact, similar in many major points."

Rosenberg, Tina.

Mission out of control. New republic, v. 190, May 14, 1984: 18-21.

Criticizes NASA's emphasis on manned missions. Contends that the spin-offs space has given us has come from unmanned programs. Warns that "the key to economically viable space manufacturing is doing the job more cheaply than on Earth. That means robotics."

Round trip to orbit: human spaceflight alternatives; special report. Washington, U.S. Office of Technology Assessment, for sale by the Supt. of Docs., G.P.O., 1989. 116 p.

"OTA-ISC-419, Aug. 1989"

"This special report examines technologies and systems for transporting astronauts and scientists to and from low-Earth orbit, and explores some of the policy choices that Congress faces in this critical aspect of the U.S. Government's space program."

Ruby, Daniel. Lampe, David.

Faster than bullets or rockets with new space-age slings: electromagnetic launchers. Popular science, v. 219, Nov. 1981: 78-81.

While the use of electromagnetism to fire small projectiles is still in the early research stages, velocities that approach the Earth's gravitational acceleration have been obtained. This fact has led to speculation that this technology could be used to launch space vehicles either from the surface of the Moon or the Earth.

Ruppe, Harry O.

European spaceflight at the crossroads. Space policy, v. 1, Nov. 1985: 390-408.

Examines how Europe can best fulfill its own objectives for future participation in space research and development.

Russell, Bertrand.

Let's stay off the Moon. Wall Street journal, July 16, 1969: 16.

Lord Russell questions whether the consquest of the moon or space can "ameliorate our human lot."

"There are some who seem to imgaine that space travel, will, of itself, lead to some cure for our terrestrial troubles. I cannot see any reason to think this. Europe had troubles before the Western Hemisphere was discovered. After it was discovered, the wars to which the old world was accustomed were transplanted to the 'new world.' Unless we amend our ways, the same thing will happen if we extend our silly empires into outer space."

Rust, David M.

Solar flares, proton showers, and the space shuttle. Science, v. 216, May 28, 1982: 939-946.

"The space shuttle era will focus renewed attention on the hazards of the space environment to human habitation. The chief unpredictable hazard for astronauts is energetic proton radiation from solar flares. In some orbits, there is no reasonable level of shielding material that will protect shuttle occupants from potentially lethal doses of radiation. The effects of a solar flare that occurred during the first flight of the Columbia are discussed and current flare research reviewed."

Ruzic, Neil P.

Why are we in space? Air University review, v. 31, Nov.-Dec. 1979: 34-48.

"Even after a fledgling 20 years of space activities, we can point to significant accomplishments by considering what the world would be like if we were not in space." The article considers some benefits of space exploration: communications, weather forecasting, energy, etc.

Sagan, Carl.

Planetary exploration. Eugene, Oregon State System of Higher Education, 1970. 76 p. (Condon lectures, 1970)

The quest for intelligent life in space is just beginning. Smithsonian, v. 9, May 1978: 38-46.

Reviews "the results of the search for extraterrestrial life. Speculates on how communication may best be made and what the effect on humanity would be if contact were made.

Saito, Shigebumi.

Japan's space policy. Space policy, v. 5, Aug. 1989: 193-200.

"Describes the formation of the Space Activities Commission as Japan's primary policy-making body, and of the National Space Development Agency, which oversees the development of space technology. The fundamental guidelines governing space activities are explained, and a detailed breakdown is given of projects agreed upon for the coming years."

Santy, Patricia.

The journey out and in: psychiatry and space exploration. American journal of psychiatry, v. 140, May 1983: 519-527.

Reviews the U.S. and U.S.S.R. research in aerospace medicine that is relevant to psychiatry and suggests ways to expand psychiatry's clinical and research usefulness in future space exploration efforts."

Schefter, Jim.

How the U.S. will be first to rendezvous with a comet. Popular science, v. 223, Oct. 1983: 102-105.

Summarizes how an old Explorer satellite will be used in an exploratory mission to the Giacobini-Zinner comet.

Orbiting telescope maps: an infrared universe. Popular science, v. 223, Dec. 1983: 88-92.

"The space telescope opens a new window on the universe. It gathers infrared radiation that penetrates interstellar dust but is absorbed in the atmosphere. Thus, the satellite is revealing never-before-seen astronomical phenomena."

Pioneer Venus. Popular science, v. 212, May 1978: 82-85, 169.

Describes how the Pioneer Venus mission will operate, what problems are anticipated, and what some of the tests will be.

Return to Mars: the big push for a manned landing begins. Popular science, no. 232, Apr. 1988: 64, 66, 68, 110-111.

"Many scientists argue that Americans and Russians--rather than competing with each other--should cooperate on a joint mission to Mars."

What are comets made of? Popular science, v. 226, Apr. 1985: 78-81.

The Search for extraterrestrial intelligence: SETI. [Washington] National Aeronautics and Space Administration, Scientific and Technical Information Office, for sale by the Supt. of Docs., G.P.O., 1977. 276 p. (U.S. National Aeronautics and Space Administration. NASA SP-419)

Partial contents.--Cosmic evolution, by I. Rasool, D. DeVincenzi, and J. Billingham.--Cultural evolution, by M. Stull.--Detection of other planetary systems, by J. Greenstein and D. Black.--The rationale for a preferred frequency band: the water hole, by B. Oliver.--Search strategies, by C. Seeger.--The science of SETI, by D. Black and M. Stull.

Seeking other worlds. Newsweek, v. 90, Aug. 15, 1977: 46-47, 49, 51-53.

Examines the hypotheses and activities of Carl Sagan, a Cornell University exobiologist who conducts extraterrestrial life experiments and who consults with NASA in the space probes.

Shapland, David. Ruycroft, Michael.

Spacelab: research in earth orbit. Cambridge [Cambridgeshire] and New York, Cambridge University Press, 1984. 192 p.

Sharp, Peter W.

Evolutionary concepts for a space station and the relevant utilisation potential. Journal of the British Interplanetary Society, v. 37, Apr. 1984: 157-162.

Describes the concepts for a U.S. manned space station and a European unmanned station.

Sheskin, T. J.

An unmanned platform as an initial capability in space. Journal of the British Interplanetary Society, v. 37, Dec. 1984: 555-558.

"An automated, unmanned space platform is proposed as a lower risk, lower cost alternative to a permanently manned space station. Many operations on a space platform are performed by telepresence controlled from the ground."

Shipman, Harry L.

Humans in space: 21st century frontiers. New York, Plenum Press, 1989. 351 p.

Considers "what are the questions, problems that will have to be addressed before our 21st-century space flight? Where should we go? What will we eat, drink, how will we stay healthy, how will we pay for it? An imaginative and entertaining collection of data, guesstimates, and plans for life 100 years from today."

Space 2000: meeting the challenge of a new era. New York, Plenum Press, 1987. 431 p.

Shklovskii, I. S. Sagan, Carl.

Intelligence life in the universe. San Francisco, Holden-Day, 1966. 509 p.

The Shuttle: sortie missions and spacelab 1. Spaceflight, v. 23, Oct. 8, 1981: 246-251.

"The Space Shuttle opens an exciting new avenue for space experimentation, the 'sortie mode.' Using this mode of operation, the Shuttle will serve in a single mission as a launch vehicle to deliver scientific equipment into low Earth orbit, as a manned laboratory for the conduct of scientific experiments, and as a re-entry vehicle to return equipment, data and specimens and samples back to the ground."

Simpson, Theodore R.

The Space Station: an idea whose time has come. Edited by Theodore R. Simpson. New York, Institute of Electrical and Electronic Engineers, 1985. 295 p.

"A collection of essays by space station experts provides brief overviews of the historical background, the way that the space station decision was made, the likely uses of the station, and its long-term potential."

Smith, Arthur.

Planetary exploration: thirty years of unmanned space probes. San Bernardino, Calif., Borgo Press, 1989, c1988. 160 p.

Smith, Bruce A.

Voyager's Neptune encounter. Aviation week & space technology, v. 131, Aug. 28, 1989: 7, 16-20.

"Voyager has made firsthand observations of the entire planetary system, the biggest bargain of the space age."

Smith, Robert W.

The space telescope: a study of NASA science, technology and politics. Cambridge, New York; Cambridge University Press, 1989. 478 p.

Describes "the history of the space telescope in the context of post-World War II science and technology and the biggest kind of 'Big Science'--scientific projects of a vast scale that involve thousands of people, require massive amounts of federal funding, and are as much political and managerial efforts as they are scientific and technical ones. The book reveals the . . . complex interactions that took place between the scientific community, government, and industry and the great range of personalities and forces--scientific, technical, political, social, institutional, and economic--that played a role in the telescope's history."

Soderblom, Laurence A. Johnson, Torrence V.

The moons of Saturn. Scientific American, v. 246, Jan. 1982: 101-115.

"The 17 icy bodies that orbit the planet display a surprising range of geological evolution. Many of them show craters more than four billion years old, but one of them has terrain so new that no craters are seen."

Solar system exploration. Journal of the British Interplanetary Society, v. 37, Oct. 1984: 433-479.

Contents.--Questions for the geologic exploration of Venus, by R. Saunders.--The Venus radar mapper mission, by E. Cutting, J. Kwok and S. Mohan.--Pioneer to Venus: the multiprobe and orbiter missions, by R. Craig and R. Fimmel.--Exploring beyond the planets: the Pioneer 10 and 11 missions, by P. Dyal and R. Fimmel.

Soviet astronautics. Journal of the British Interplanetary Society, v. 41, Mar. 1988: whole issue (105-144 p.)

Partial contents.--The Soviet cosmonaut team 1978-1987, by Rex Hall.--The Soviet manned lunar programme and Soyuz missions 1-5, by P. Mills.--The evolution of the Prognoz series of solar observations, by B. Harvey.--Simple analysis of space station downlinks, by J. Branegan.

Soviet manned spaceflight: blueprint for the future. Aviation week & space technology, v. 129, Dec. 12, 1988: 44-46, 51, 54.

Contents.--Long-term space plan will lead to Soviet orbital infrastructure, by Jeffrey M. Lenorovitz--Soviets base six-engine transport for shuttle, booster on An-124.

Space-based remote sensing of the Earth; a report to the Congress; prepared by the National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, and National Aeronautics and Space Administration. Washington, For sale by the Supt. of Docs., G.P.O., 1987. 123 p.

This report "represents the start of the planning process to develop an integrated national program for research and development in Earth remote sensing for the remainder of this century and describes the many existing and proposed satellite and sensor systems that the program may include."

Space medicine faces massive tasks as humans venture farther from earth. JAMA [Journal of the American Medical Association], v. 256, Oct. 17, 1986: 2009-2052 passim (20 p.)

Presents a series of short reports on the future of space medicine.

The Space program--pro and con. Space world, v. H-12-96, Dec. 1971: 32-35.

The Space settlement papers. Journal of the British Interplanetary Society, v. 39, July 1986: 291-311.

This group of papers was written by the Space Settlement Working Group, private citizens concerned with the human aspects of space development, and submitted to the National Commission on Space.

Space Shuttle. Discover, v. 6, Nov. 1985: 29-31, 34-35, 38, 40-41, 45, 48-49, 52-54, 56-58, 64-67, 70-77.

"The space shuttle was supposed to land at commercial airports, serve as a gravity-free lab for working scientific miracles, and pay for itself. So far, it has put the U.S. billions in the hole and, as this three-part Special Report reveals, has made far fewer flights and provided a lot less science than predicted."

Contents.--The Shuttle: triumph or turkey?, by A. Roland.--Success amid the snafus, by D. Overbye.--The new American Frontier, by G. O'Neill.

Space station. Aerospace America, v. 26, Nov. 1988: 18-22, 24-26, 28-30.

Contents.--Designing for operations and support, by Thomas M. Crabb, James T. Kaidy, and William G. Bastedo, Jr.--Toward station operability, by Gregory R. Bennett and Stephen G. Paddock.--The orbital maneuvering vehicle, by Arthur G. Stephenson.--Getting more out of EVA, by Fred Abeles.

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Charting the course: U.S. space enterprise and space industrial competitiveness; report of the Commercial Programs Advisory Committee. Washington, National Aeronautics and Space Administration, 1989. 72 p.

The Commercial Programs Advisory Committee was formally created in 1988. It is a subcommittee of the NASA Advisory Council.

"New commercial opportunities for business and the potential for national economic growth are emerging in several markets, notably launch services and space facilities. Business appears poised to take the lead in developing other new space-based enterprises. The most promising markets include the following: satellite applications . . .; launch capabilities for transporting satellites and structures into space . . .; facilities for working in space . . .; [and] research and development opportunities."

Chen, Kan. Chang, Nicholas.

Technology forecast of space robots to the year 2000. Technology forecasting & social change, v. 26, Aug. 1984: 47-57.

"This paper addresses the technological capabilities of robotics systems to perform assembly and maintenance functions of the space station program in the time frame of 1995 to 2000."

Christol, Carl Q.

Stratospheric ozone, space objects, and international environmental law. Journal of space law, v. 4, spring 1976: 23-31.

Author discusses the environmental impact of space vehicles from two points of view; as a source of pollutants from rocket engine effluents and use of satellites to monitor environmental pollution of the upper atmosphere.

Clark, Phillip S.

Chinese launch vehicles aim for the commercial market. Space markets quarterly, no. 4, winter 1987: 178-185.

Presents information on China's satellite launch vehicle program and describes the Chinese facilities that will support commercial satellite missions.

Cobb, Jean. Montgomery Peter.

Space for rent. Common cause magazine, v. 14, Mar.-Apr. 1988: 12-14.

"Details a White House plan to have the National Aeronautics and Space Administration (NASA) spend $700 million to rent a private orbiting research lab, despite opposition in NASA to using its funds to subsidize the private venture."

Cohen, Alexander F.

Cosmos 954 and the international law of satellite accidents. Yale journal of international law, v. 10, fall 1985: 78-91.

"The norms established by the Cosmos 954 incident provide that the major satellite-launching nations--the U.S and the U.S.S.R.--notify each other of hazardous events due to satellite failure, relay information to facilitate damage control, assist their political allies in cleanup operations, and share the cost of compensating the state injured by a falling satellite, regardless of whose satellite casued the injury and regardless of fault."

Colino, Richard R.

Global politics and INTELSAT. Telecommunications policy, v. 10, Sept. 1986: 195-208.

Argues that the U.S. plan to license satellites in competition with INTELSAT would be globally divisive, harm developing nations and boost the rival INTERSPUTNIK. Calls for the U.S. to continue to operate through INTELSAT.

INTELSAT's twentieth anniversary: two decades of innovation in global communications. Telecommunication journal, v. 52, Jan. 1985: 22-31.

Relates the growth and achievements of INTELSAT since 1965 when its first geosynchronous satellite was launched. Predicts continued technical advances and growing importance for INTELSAT as it brings modern communications systems to the most isolated regions of the world.

Collins, Michael.

An astronaut's look at commercial space opportunities. Commercial space, v. 1, spring 1985: 24-26.

The author outlines the qualities of space which are of interest in planning commercial ventures and suggests several manufacturing projects which could be profitable. He discusses the role of the Federal Government in assisting and regulating commercial space activities and the future role of the U.S. space shuttle.

Colombo, Giuseppe.

Space technology: where will fiction meet reality? Technology review, v. 84, Oct. 1981: 69-77.

"The fact that we have not yet undertaken many technically feasible projects to bring the resources of space to bear on our urgent needs on earth suggests that the line between reality and fiction depends not on science but on social and political factors."

Commercial newsgathering from space; a technical memorandum. Washington, Office of Technology Assessment, 1987. 49 p.

"OTA-TM-ISC-40"

"The news media have begun to increase the use of satellite imagery in reporting on world events. This has led some to believe that the media will soon wish to own and operate their own remote sensing systems dedicated to newsgathering. The media have generally supported the idea of a dedicated 'mediasat' because it could supply a stream of timely and critical information, peering where repressive governments or dangerous natural environments have heretofore kept the press at bay. However, the media's use of this potentially intrusive technology could create national security problems, complicate U.S. foreign relations, and, perhaps, erode the average citizen's expectation of personal privacy."

Commercialization of land and weather satellites; report prepared by Science Policy Research Division, Congressional Research Service, for the Subcommittee on Space Science and Applications and the Subcommittee on Natural Resources, Agriculture Research and Environment transmitted to the committee on Science and Technology, U.S. House of Representatives, 98th Congress, 1st session. Washington, G.P.O., 1983. 365 p.

At head of title: Committee print.

"Serial H"

Commercialization of space. Aviation week & space technology, v. 120, June 25, 1984: 40-201.

This collection of articles covers such topics as economic policies to stimulate space commercialization, processing of materials and drugs in space, Landsat commercialization, and the viability of commercial space ventures.

Condara, Christie.

Outer space, like the sea and the air, whose frontier? Incredible potential with inscrutable obstacles. Houston journal of international law, v. 6, spring 1984: 175-196.

"This comment attempts to broadly survey the development of sea, air, and space law to determine if lessons that have been learned in the first two areas might suggest patterns for the third. It describes the Earth's frontiers and the developments occurring in each of them. The legal issues involved in using sea, air, and space resources are also addressed. Finally, the problems and prospects of free enterprise in outer space are reviewed."

Copulos, Milton R.

Enterprise in orbit: the commerical potential of space. Washington, Heritage Foundation, 1984. 9 p. (Backgrounder no. 392)

Predicts that there will be extensive colonization and industrialization of space by the year 2050. Argues that this can best be achieved by the private sector and that government's role should be limited to providing a legal framework, encouraging exploration, and providing for defense.

Removing obstacles to the commercial development of space. Washington, Citizens for a Sound Economy, 1985. 16 p. (CSE issue analysis no. 6)

"It's no surprise the [Grace Commission] task force failed to make any new suggestions regarding National Aeronautics and Space Administration] privatization. They relied exclusively on individual and documents which were either directly or indirectly associated with NASA. What makes their failure all the more ironic is that a strong case exists for a purely private space enterprise."

Corrigan, Richard.

The fiber optics future. National journal, v. 18, June 7, 1986: 1371-1374.

"Communictions firms are lining the globe with glass cables that can transmit the contents of libraries in seconds. Their satellite competitors are on the defensive."

Haves and have-nots are competing for a piece of a ring around earth. National journal, v. 17, Oct. 26, 1985: 2406-2412.

"Third World nations object to the first-come, first-served plan for allocating satellite orbit positions. To the United States's dismay, the system may soon change."

Hitchhiking to space. National journal, v. 18, July 5, 1986: 1653-1657.

"Earthbound by the shuttle disaster and rocket crashes, the Administration is looking at the role the private sector might play in getting it back into space." States that U.S. aerospace companies don't want to get into the commercial launch business because of the risks, high costs, and the fact that they would have to compete with foreign launch services which are subsidized by their governments.

Covault, Craig.

Economic competition. Commercial space, v. 1, fall 1985: 18-21.

"The battle is heating up between the U.S. shuttle and European Ariane for the worldwide commercial payload market.

Evolving government policy eases way for space ventures. Commercial space, v. 1, spring 1985: 14-18.

Describes current NASA initiatives to stimulate private investment in space. Notes that the Administration's commercial space policy, which has introduced greater predictability into corporate planning for space ventures, has drawn a diverse group of participants toward the commercial space field.

Cowen, Robert C.

The high frontier. Christian Science monitor, Sept. 25, 1984: 16-17; Sept. 26: 16-17.

In this two part article, the author explores the "race to develop industrial capacity in space." Compares the U.S. space program for industrialization with that of the Europeans.

Cowhey, Peter F. Aronson, Jonathan D.

The great satellite shootout. Regulation, v. 9, May-June 1985: 27-35.

Relates the history of Intelsat and Comsat and the FCC's current movement toward allowing competition in satellite telecommunications. Voices the regulatory issues which will be raised as to pricing, access, coordination, and competition from foreign carriers entering the U.S. telecommunication market.

Crawford, Alan Pell.

An "industrial policy" for space. Washington, Cato Institute, 1986. 30 p. (Policy analysis no. 69)

"Of the policy recommendations under consideration, almost all would strengthen the federal government's domination of space commercialization. Federal control represents a serious obstacle to true commercialization, if by that one means a business environment in which the forces of the market, not the whims of the federal government, dominate."

Criswell, David. Marsh, Peter.

Working on the moon. New scientist, v. 92, Oct. 1, 1981: 30-33.

"If people are serious about making goods in space, then the natural place where we should both mine materials and site factories is our nearest neighbour in the Solar System--the Moon."

Croom, D. L.

Climate research from space. Journal of the British Interplanatery Society, v. 37, July 1984: 323-329.

Culbertson, Philip E.

Using space. Chemtech, v. 15, Apr. 1985: 214-217.

Defines the characteristics of space which make it a useful location for commercial ventures. Describes experiments which have been conducted thus far on U.S. space flights and NASA's procedures for encouraging the private sector to participate in research and development activities in space.

Cunningham, Richard D.
Space commerce and secured financing--new frontiers for the U.C.C. [Uniform Commercial Code] Business lawyer, v. 40, May 1985: 803-838.
"Article explores the issues of commercial, constitutional, and international law that affect the taking of a security interest in privately owned property located in space, recommends techniques for creating and protecting those security interests under present law, and proposes federal legislation to resolve some of the problems in this emerging field."

Curtis, Anthony R.
New satellites make ham fun. Popular mechanics, v. 145, Feb. 1976: 76-78, 131-132.
"You can tune in the fascinating worldwide network of amateur radio buffs whose 'homebuilt' satellites orbit in space."

DalBello, Richard.
The Land Remote Sensing Commercialization Act of 1984. Space policy, v. 1, Aug. 1985: 289-297.
"This article examines the effect that private-sector remote sensing activities might have on the international community and on the future of international cooperation in space."

Danilenko, G. M.
Space technology and marine scientific research. Marine policy, v. 12, July 1988: 247-255.
"This article looks at the role of space technology in marine scientific research. It discusses the uses of remote sensing and its principles and relevant international law."

Davis, Neil W.
Japan takes charge. Aerospace America, v. 26, Mar. 1988: 22-26.
Reports on various space programs in Japan including the H-2 launch vehicle, a suborbital minishuttle and the aerospace plane.

Japan's race toward space profits. Aerospace America, v. 23, Dec. 1985: 16, 18, 20, 22.
"Spurred by their government, groups of Japanese companies are teaming up to prepare for commercial space ventures."

Davis, Robert A.
Technology base for the future of space. Aerospace America, v. 24, July 1986: 44-47.
"The civil space program should yield tangible benefits to all mankind. To support this fundamental tenet of U.S. space policy and offer the widest range of future options, the civil space program should cultivate the strongest possible base of science and technology."

DeMeis, Richard.
China's springboard to space. Aerospace America, v. 26, Mar. 1988: 16-20.
Describes China's Xichang satellite launch center. By launching foreign satellites, China acquires technological expertise and foreign capital.

Deudney, Daniel.
Coming down to Earth: industry in space is a mirage of abundance. Across the Board, v. 19, Nov. 1982: 41-45.
"Although space manufacturing may become a modest industry some day, large-scale space industrialization is an unworkable attempt to escape from the problems of earth."

Dooling, Dave.
Orbital processing promises investors immediate financial rewards. Commercial space, v. 1, summer 1985: 14-20.
"A mature materials processing in space program (MPS) is expanding nationwide from the National Aeronautics and Space Administration's primary materials processing operations base here at the Marshall Space Flight Center, and it is playing a key role in the planning of several space shuttle missions. It also is influencing the design of one of the laboratory modules for the U.S. space station."

Shift in shuttle's space-station role? .Aerospace America, v. 25, Sept. 1987: 6-9, 72, 74-76, 78.

"Heavy demands that space-station assembly is expected to place on the shuttle, competition in the international market for launch vehicle services, and concerns over orbiter stress and fatigue are causing the Reagan administration and Congress to reevaluate the Shuttle's role in the national space program."

Downs, Hugh.
The resources of space. Center magazine, v. 9, July-Aug. 1976: 67-75.

Author argues for continued support of the United States space program which he sees providing the breakthroughs necessary to solve many of mankind's problems, i.e. energy from solar satellites, space colonies, etc.

Dula, Art, and others.
Symposium: the role of private enterprise in outer space--international legal implications. Houston journal of international law, v. 2, autumn 1979: 1-166.

Contents.--Free enterprise and the proposed Moon Treaty, by A. Dula.--Earth space transport systems--concepts, criteria & constraints, by W. Good.--Product liability in space law, by P. Haanappel.--Outer space law and private enterprise in outer space: an international perspective, by G. Reijnen.--Space industrialization and the legal status of astronauts: start of a jurisdictional head scratcher, by G. Robinson.--Outer space delimitation proposals: enlightened jurisprudence or celestial shakedown? Some implications for private enterprise, by G. Sloup.--International utilization and management of space systems, by D. Smith.--Hail? No--it's Skylab, by J. Tamm.--Outer space: a preserve for all human kind, by L. Tennen.

Dula, Arthur M.
Export controls affecting space operations. Journal of air law and commerce, v. 51, summer 1986: 927-950.

This article concludes "our best chance for true security lies in allowing rapid exchange of ideas and products between the free nations of the West. The West must stay ahead in the race to develop the resources and potential uses of space for the benefit of all humanity. This race cannot be won if the West copies the paranoid secrecy of its despotic opponents."

Easterbrook, Gregg.
Big dumb rockets. Newsweek, v. 110, Aug. 17, 1987: 46-50, 52-54, 57-58, 60.

Reports the events of Big Dumb Booster, a project to develop a high performance, low cost booster rocket. The idea, conceived by Arthur Schmitt, an engineer at Aerospace Corp., could save NASA billions of dollars in shuttle expenses.

Economics and technology in U.S. space policy; proceedings of a symposium held in Washington, D.C., June 24-25, 1986. Molly K. Macauley, editor. Washington, Resources for the Future, 1987. 270 p.

Proceedings of a symposium held in June 1986 convened "to discuss emerging economic and technological issues in space policy." Addresses questions about "the proper role of markets and institutions in establishing incentives for effective use of space resources, and what arrangements constitute the most productive relationships between government and commercial endeavors in space."

Edelson, Burton I. Cooper, Robert S.
Business use of satellite communications. Science, v. 215, Feb. 12, 1982: 837-842.

"The principal services provided by satellite systems have been long-distance trunks for telephone circuits and television program distribution. Recently, data transmission and network services have been added to meet emerging requirements for 'office of the future' and other business applications. Data services are now expected to be the most rapidly expanding element of satellite communications."

Edwards, Diane E.
Giving space the business. Science news, v. 128, Dec. 21 & 28, 1985: 392-395.

"Although there is speculation about large profits from 'made in space' goods, the true extent and feasibility of space industry are still unknowable."

Ehricke, Krafft A.
The extraterrestrial imperative. Futures, v. 13, Apr. 1981: 107-114.
Claims that "the industrial use of space offers new and better services, new and better products, broader access to energy sources and their use outside the biosphere, and new capabilities in general."

Engle, Michael.
Soviet industrial activities in space. National defense, v. 73, Sept. 1988: 35-37.
Describes the Soviet Union's Mir space station research in materials processing in space and their efforts to begin large-scale industrial activities in orbit.

Engler, Nick. Cheshire-Engler, Donna.
Life after liftoff. Omni, v. 5, May 1983: 108, 110, 112, 133.
"Space doctors, caught up in the enthusiasm of an emerging science, love to speculate. They hope that eventually space biology, psychology, and sociology will produce yet another spinoff: space civilization."

Esposito, Francis H.
The commercial exploitation of space. Air Force law review, v. 25, no. 2, 1985: 159-167.
This Comment briefly reviews the Commercial Space Launch Act and it contends that U.S. policy consistently supports private enterprise in space.

Feazel, Michael.
Germany cites commercial fallout as justification for U.S. station involvement. Commercial space, v. 1, spring 1985: 47, 49, 51, 54.
"Future commercial return is the condition on which West Germany's government agreed to participate in the U.S. space station, and that condition will apply to commitments to other new space projects."

Finch, Edward R.
Astrobusiness: a guide to commerce and law of outer space. New York, Praeger, 1985.

Foley, Theresa.
ELVs. Commercial space, v. 2, fall 1986: 16-21.
"U.S. manufacturers begin the job of rebuilding the U.S. space program: with the shuttle out of the competition, users are turning to expendables."

Microgravity Task Force recommends sweeping changes to NASA program. Aviation week & space technology, v. 127, July 20, 1987: 50-51.

Footer, Sheila.
Legal issues and answers for commercial users of the space shuttle. Transportation law journal, v. 15, no. 1, 1983: 87-101.
Article contends that "the challenge for the next decade not only will be technological--it also will be legal, for there are few 'experts' now in space law. Commercial users are going to require some 'experts,' however, to answer some difficult questions before they make a substantial financial commitment to use the shuttle. NASA and the legal community must recognize the concerns of the private users, and attempt to resolve them in a manner equitable to all. The future of commercial endeavor in space depends on it."

Furniss, Tim.
Earth resources. Flight international, v. 128, Nov. 2, 1985: 26-29.
Explains the development and operation of the Landsat system and the significance of the data which it collects. NOAA has operated the system since 1983 but the U.S. Government is attempting to commercialize it. Eoasat will operate the system, but some government subsidies will continue.

Enterprise in orbit. Flight international, v. 137, Feb. 21-27, 1990: 41-49.
States that "the only space activity that makes money is building, launching and operating commercial communications satellites." Contains a listing of world communication satellites.

Japan's rise in space. Flight international, v. 130, Oct. 11, 1986: 28-31.
"Japan's single-minded, low-profile, but immensely successful approach to space research and exploitation has placed it near the top of the world's space league."

Launch vehicles: countdown for a piece of the action. Flight international, v. 133, Feb. 20, 1988: 21-25.
"Surveys the present and possible future of the worldwide satellite launch vehicle industry to the end of the century."

Future orbital power systems technology requirements. [Washington] National Aeronautics and Space Administration, Scientific and Technical Information Office, 1978. 319 p. (NASA conference publication 2058)
"A symposium held at Lewis Research Center, Cleveland, Ohio, May 31 and June 1, 1978."
"The purpose of this meeting was to give leaders from government and industry a broad view of current government-supported technology efforts and future program plans in space power."

Gaffey, Michael J. McCord, Thomas B.
Mining outer space. Technology review, v. 79, June 1977: 50-59.
"Asteroids contain many of the minerals in short supply on earth. Detecting and recovering these minerals could be technically feasible and financially rewarding."

Gavaghan, Helen.
Space business. New scientist, v. 116, Dec. 3, 1987: 1-4.
Describes the interests to commercial businesses in communications, remote sensing and microgravity application satellites. Businesses see investment in them as a new source of business profit.

Get away special . . . the first ten years. Greenbelt, Md., Goddard Space Flight Center, Special Payloads Division, 1989. 40 p.
"The National Aeronautics and Space Administration's (NASA's) Get Away Special Program has been unique in the aerospace world for the exceptional range of nonprofessional and professional experimenters who have gained access to space through it . . . . This brief history begins with the origins of the Get Away Special Program in The Concept section. It continues to tell of milestones in the program's development in the STS Mission Descriptions. Perhaps most interesting, particularly to potential experimenters, are the overviews of individual customer payloads, chronologically grouped with their respective Shuttle missions."

Glazer, J. Henry.
Domicile and industry in outer space. Columbia journal of transnational law, v. 17, no. 1, 1978: 67-117.
"The . . . economic exploitation of the outer space segment of transnational space presents a major and tangible challenge to contemporary national and international law-makers. A failure to establish rational foundations for utilizing the outer space segment within the present context of international law will create obstacles to future space settlement and industrialization."

Goddard Memorial Symposium (18th: 1980: Washington, D.C.)
Commercial operations in space, 1980-2000. Edited by John L. McLucas, and Charles Sheffield. San Diego, Calif., Published for the American Astronautical Society by Univelt, 1981. 201 p. (Science and technology series; v. 51)

Goldman, Nathan C.
Space commerce: free enterprise on the high frontier. Cambridge, Mass., Ballinger Pub. Co., 1985. 186 p.

Goodrich, Jonathan N.
Business in space: the new frontier? By Jonathan N. Goodrich, Gary H. Kitmacher, and Shard R. Amtey. Business horizons, v. 30, Jan.-Feb. 1987: 75-84.

"Space exploration and development may be for the twenty-first century what aviation, electronics, and computers, taken together, represent for the century nearing completion. What are the opportunities and obstacles in space commercialization? And what are the marketing implications of this new frontier?"

The commercialization of outer space: opportunities and obstacles for American business. New York, Quorum books, 1989. 211 p.

Gorove, Stephen.
Expectations in space law: a peek into the future. Journal of international affairs, v. 39, summer 1985: 167-174.

"During the short span of less than three decades, we have witnessed a spectacular growth in legal doctrines and practices related to man's activities in outer space . . . . With respect to space law one of the significant influencing factors that shaped and will be shaping the law appears to relate to scientific and technological advances . . . . This presentation will focus on some of the legal issues which are likely to arise in the decades immediately ahead: space stations and human settlements in free space and on celestial bodies; solar power satellites; the geostationary orbit, direct broadcast satellites, remote sensing."

Gould, Charles L. Gerber, C. R.
Skynet 2000. Futurist, v. 17, Feb. 1983: 4-9.

Contends that "by the year 2000, a new system of communicating via space will distribute the benefits of the information revolution around the globe, making productivity jumps possible even in isolated areas of the Third World."

Greeley, Brendan M., Jr.
Commercial marketing of Landsat data begins. Commercial space, v. 1, fall 1985: 66-69.

The formation of the Earth Observation Satellite Co. (EOSAT) marked the beginning of commercial marketing of Landsat data.

Grey, Jerry.
Government vs. free enterprise in space. Dallas, National Center for Policy Analysis, 1987. 28 p. (NCPA policy report no. 126)

"Burdensome regulations and vacillating and erratic federal policies have seriously impeded the U.S. space industry in its efforts to take advantage of our greatest asset--the vitality and productivity of the American free enterprise system . . . . By far the most important step the government could take to encourage the private industrial development of space would be the development of a long-term national plan to guide NASA and other relevant agencies and to give the private sector a firm basis for investment."

Implications of the shuttle: our business in space. Technology review, v. 84, Oct. 1981: 34-42, 44, 46.

Explores the commercial possibilities of the space shuttle. Calls for "imaginative public-private partnerships" to assure commercial success.

Investing in space: now, soon, or later? Aerospace America, v. 22, Apr. 1984: 90-92.

Examines the economic viability of space enterprise.

Making the grade. Omni, v. 10, July 1988: 71-72, 74-75.

Compares the space launch capabilities of six countries: U.S., Soviet Union, European Space Agency members, Japan, China, and India.

Gump, David.
Space enterprise: beyond NASA. New York, Praeger, 1990. 220 p.

Gwynne, Peter.

Shuttle woes raise doubts of cost-effective turnaround. Industrial research & development, v. 24, Jan. 1982: 68-70, 72.

Questions the economic viability of the space shuttle.

Haggerty, James J.

The outlook for space commercialization. Aerospace, v. 22, winter 1984: 2-7.

Foresees growth of commercial space ventures and expanded private sector investment in space commercialization.

Spinoff 1989. Washington, U.S. National Aeronautics and Space Administration, Technology Utilization Division, for sale by the Supt. of Docs., G.P.O., 1985. 136 p.

Spinoff 1989 is organized in three sections:--Section 1 outlines NASA's mainline effort, the major programs that generate new technology and, therefore, replenish and expand the bank of knowledge available for transfer.--Section 2, the focal point of this volume, contains a representative sampling of spinoff products that resulted from secondary application of technology originally developed to meet mainline goals.--Section 3 describes the various mechanisms NASA employs to stimulate technology and lists, in an appendix, contact sources for futher information about the Technology Utilization Program.

Hagler, Thomas. Patterson, Herbert G. Nathan, C. Allan.

Learning to build large structures in space. Astronautics & aeronautics, v. 15, Dec. 1977: 51-57.

Discusses "the key pieces of technology and construction know-how that have to be developed first and a flight program to verify them," in order to construct large structures in space.

Haise, Fred W., Jr.

Hardhats in space. Space world, v. Q-5-197, May 1980: 6-13.

Conceptualizes the conditions for "astroworkers", those who will construct platforms, factories and observatories in outer space.

Hanks, Brantley R. Pinson, Larry D.

Large space structures raise testing challenges. Astronautics & aeronautics, v. 21, Oct. 1983: 34-40, 53.

"We must have a program now to combine model, component, and subassembly tests with flight experiments on simple structures to assure safe and efficient large spacecraft."

Harr, Michael. Kohli, Rajiv.

Commercial utilization of space: international comparison of framework conditions. Columbus, Battelle Press, 1989. 162 p.

Harrigan, Stephen.

Mr. Hannah's rocket. Texas monthly, v. 10, Nov. 1982: 168-173, 272-284.

David Hannah, Jr. has a dream to build a privately financed commercial space vehicle, and his successful September launch of Conestoga I from Matgorda Island suggests that it might just come true.

Harris, Michael.

The junk in outer space; pollution of the worst kind. Progressive, v. 42, Nov. 1978: 16-19.

Warns against the proliferation of "space junk" in earth orbit and the increasing use of space for military purposes by the U.S. and the U.S.S.R.

Hartmann, William K.

Mines in the sky promise riches, a greener Earth. Smithsonian, v. 13, Sept. 1982: 71-76.

Foresees the mining of asteroids for metals needed on Earth.

Hawkridge, D. G.

Satellites and education: prospects and problems. Journal of the British Interplanetary Society, v. 30, Apr. 1977: 147-154.

World wide survey of the use of communication satellites in education.

Hazelrigg, George A. Hymowitz, Madeleine E.
Space commercialization: lessons from history. Space policy, v. 1, May 1985: 187-201.
"Two major factors inhibiting further space commercialization are the current lack of necessary infrastructure and the lack of viable commercial activities. The necessary infrastructure is developing with the increasing operational status of the Space Shuttle and plans for a space station. It remains, however, to place increasing emphasis on the conduct of research in space to identify valid commercial uses of space."

Heiss, Klaus P.
A perspective on private initiatives in U.S. space transportation. Journal of social, political and economic studies, v. 11, spring 1986: 3-16.
Defends the 1972 decision to proceed with space shuttle development and describes how budgetary concerns compromised the program and finally led "to economic and technical disaster." Recommends that no new Orbiter of the same design be built, that the private sector be encouraged to develop expendable launch vehicles, and that new technology Orbiters be developed for the 1990s.

Space: the new economic frontier. Journal of social, political and economic studies, v. 11, winter 1986: 367-377.
Calls for free market principles for space activities.

Henbest, Nigel.
Astronomy--the next space race. New scientist, v. 97, Mar. 31, 1983: 896-900.
"As the European Space Agency chooses its next astronomy satellite this week, the 1980s promise a 'space race' where the leaders will not be the United States, but Europe and Japan."

Hertzfeld, Henry R.
Launch vehicles and the commercial uses of outer space. Space policy, v. 1, Nov. 1985: 379-389.
Claims that "because of the mixing of government and private uses for space vehicles, traditional economic analysis provides only a starting point for policy decisions."

Rebuilding US launch capabilities. Space policy, v. 3, May 1987: 100-103.
"Argues in favour of a proposal to establish a quasi-governmental corporation for space launches which would both safeguard the interests of government and commercial users and ensure that business acumen was applied."

Hi-tech America. Science digest, v. 93, Mar. 1985: 33-87 passim (24 p.)
Contents.--Boom or bust on the new frontier, by M. Rogers.--Winners: five who made it young, by R. Ressmeyer and A. Mereson.--Space Inc., by R. Martin.--Cashing in on biotech, by R. Rothenberg.--The image maker, by S. Hammer.

Human factors of outer space production. Edited by T. Stephen Cheston and David L. Winter. Boulder, Colo., Published by Westview Press for the American Association for the Advancement of Science, 1980. 206 p. (AAAS selected symposia series; 50)

Hunt, Garry. Fifield, Richard.
Remote sensing and the whole world picture show. New scientist, v. 115, Aug. 20, 1987: 46-51.
"A growing range of artificial satellites, sensors and computers is bringing new insights of the Earth's surface for use by farmers, meteorologists, geologists," the military, map makers and fishermen.

Industrialization of space: proceedings of the 23rd AAS annual meeting, October 18-20, 1977, San Francisco, California. Edited by Richard A. Van Patten, Paul Siegler, E.V.B. Stearns. San Diego, Published for the American Astronautical Society by Univelt, 1978. 2 v. (1121 p.) (Advances in the astronautical sciences; v. 36) (An American Astronautical Society publication)

Internationalizing the space station. Commercial space, v. 1, winter 1986: 18-23, 25-29, 31-34, 37, 39, 41-43, 46-48, 49-53.

Jaffe, Harry.

The black eye in the sky. Regardie's, v. 7, Mar. 1987: 122-130, 132-133.

"What happened to America's dominance of this emerging industry [remote sensing]? This isn't a case of advanced technology being stolen, leaked, or given away to foreign competitors. Regretably, it's a case of the U.S. government killing a cash cow in space to save a few bucks on earth."

Jericho, Eugene. McCracken, David G.

Space law: is it the last legal frontier? Journal of air law and commerce, v. 51, summer 1986: 791-808

This article reviews aspects of international law which have already been incorporated into space law and indicates issues which need to be addressed. Discusses legal issues which will arise from the growing areas of commercial enterprise and from the space insurance field.

Jordan, Don.

Looking in on us. Environment, v. 19, Aug.-Sept. 1977: 6-11.

Discusses the development of remote sensing technology and some of the questions being raised, e.g., invasion of privacy, free access to data, and international cooperation.

Joyner, Christopher C. Miller, Douglas R.

Selling satellites: the commercialization of LANDSAT. Harvard international law journal, v. 26, winter 1985: 63-102.

This article discusses the administration's proposed plan for transfer of the Landsat program to private operators who would be responsible for the acquisition, analysis, and sale of data. The authors analyze the economic, political, and legal repercussions and conclude that the LANDSAT program should be maintained under government ownership and operation.

Karlin, Beth.

Starship enterprise. Omni, v. 10, July 1988: 51-52, 56-57, 104, 106.

Describes the activities of a few private companies which are designing launch vehicles for transporting materials, satellites, food, etc. into space.

Klotz, Irene.

Spaceport 2000. Ad astra, v. 1, Feb. 1989: 39-42.

Describes activities in Florida and Hawaii in anticipation of industrial space transportation needs of the future and of developing launch centers for commercial ventures.

Kolm, Henry. Mongeau, Peter.

An alternative launching medium. IEEE spectrum, v. 19, Apr. 1982: 30-36.

"For launching the massive quantities of cargo needed for significant space operations--permanent laboratories, telescopes, manufacturing, or mining facilities--chemical rockets are too costly and environmentally destructive. Electromagnetic launchers, sited on earth, would not have these limitations. They could project almost pure payload, with minimal loss of hardware, and therefore the launching cost could be made to approach the cost of the energy--currently 65 cents per pound--plus capital amortization, which depends on the rate of use."

Kosmo, Fred.

The commercialization of space: a regulatory scheme that promotes commercial ventures and international responsibility. Southern California law review, v. 61, May 1988: 1055-1089.

This comment contends that in order to encourage "commercial entities to invest in space, a comprehensive regulatory scheme must be enacted. The proposed system should provide private enterprise with long-term predictability and a minimum of regulatory interference. The scheme also accounts for the fact that space is an international territory by recognizing the rights of other space participants."

Kraselsky, Bruce D.

Space commerce: an industry assessment. Washington, U.S. Dept. of Commerce, 1988. 136 p.

Kubbig, Bernd W.
Military-civilian spin-off: promises, premises and problems. Development and peace, v. 7, autumn 1986: 199-227.

"Opinion is sharply divided on the value of space-related technology to the commercial economy. Space enthusiasts extoll the earthly benefits harvested as spin-offs from the missile and space programs and make predictions of many more to come. Skeptics point to errors in these claims and maintain that spin-off benefits have been--and will be--relatively minor."

Kuzela, Lad.
Who'll win the race for profits in space. Industry week, v. 222, Aug. 6, 1984: 28-31.

Some analysts see a hesitancy on the part of American business to commit substantial resources toward space commercialization ventures. They see the possibility of Japan and Europe taking a leading role in space business.

Launch options for the future: special report. Washington, Office of Technology Assessment, for sale by the Supt. of Docs., G.P.O., 1988. 100 p.

"OTA-ISC-383, July 1988"

"Describes the range of launch systems that exist now or could be available before 2010 and explores the costs of meeting different demand levels for launching humans and spacecraft to orbit." Also "discusses the importance of developing advanced technologies for space transportation."

Laver, Michael.
Public, private and common in outer space: res extra commercium or res communis humanitatis beyond the high frontier? Political studies, v. 34, Sept. 1986: 359-373.

"The main purpose of this paper is to explore the response of decision-makers to the potential for tragedies in outer space . . . . Most of outer space is simply not susceptible to effective control by terrestrial beings. Yet activity by earth-based decision-makers could clearly result in space tragedies, the most obvious of which arise from the use of nuclear weapons."

Lawrence, Robert Z.
Can America compete? Washington, Brookings Institution, 1984. 156 p.

Partial contents.--A nation of hamburger stands?--Is America deindustrializing?--Is trade deindustrializing America?--Structural change in industry.--The questionable case for selective industrial policies.--Toward more appropriate sturctural policies.

Lepkowski, Wil.
U.S. space policy ready for next big leap. Chemical & engineering news, v. 62, Feb. 1984: 9-16.

Looks at future commercialization of space technology including satellites, research and development in space and the future military uses of space by the U.S.

Lerner, Eric J.
Superconductors heat up aerospace. Aerospace America, v. 25, Oct. 1987: 14-17.

Discusses the revived interest in the application of superconductor technology especially in electromagnetic spacecraft launchers and magnetic levitation trains.

Levine, Arthur L.
Commercialization of space: policy and administration issues. Public administration review, v. 45, Sept.-Oct 1985: 562-569.

"The Reagan administration has made commercialization a cornerstone of its space program. In the thrust to propel private enterprise into space, significant policy and administration issues are being neglected, both in the government and by academic and professional observers."

Lewis, John S. Lewis, Ruth A.
Space resources: breaking the bonds of earth. New York, Columbia University Press, 1987. 418 p.

Lindgren, David T.

Commercial satellites open skies. Bulletin of the atomic scientists, v. 44, Apr. 1988: 34-37.

Discusses the potential for commercial satellite remote sensing especially as sources of information for policy makers and the public. An "open sky" policy is gaining support, which could result in fewer restraints on freedom of information exchange and mutual space surveillance.

Llewellyn-Jones, David.

An eye in the sky for Europe. New scientist, v. 118, May 5, 1988: 59-62.

"In 1990 Europe will launch its first remote sensing satellite. It should lead to a better understanding of the forces that drive the world's weather."

Lobanov, Igor.

Sea watchers in space: interpreting the movements of the sea. Oceans, v. 14, Nov.-Dec. 1981: 39-43.

"Already, imagery from satellites is producing a tremendous volume and variety of information--much more than simply wind and wave data. This onslaught of information, fed into computers and translated into pictures, is providing oceanographers and other researchers a vast array of answers."

Loftus, Joseph P., Jr. Tilton, E. Lee. Temple, L. Parker, III.

Decision time on orbital debris. Aerospace America, v. 26, June 1988: 16-19, 22-25.

Space debris has become so abundant that it poses a collision hazard to new spacecraft. Four articles describe the efforts to protect existing and new spacecraft from debris.

Logsdon, John M.

Status of space commercialization in the USA. Space policy, v. 2, Feb. 1986: 9-15.

"This article considers the status of space commercialization in the USA and suggests that recent developments present a pessimistic picture. What progress there has been is in settling in for the long-run task of building the research base and infrastructure required for the realization of space-based commercial activities."

Lowenstein, Frank.

Seasons, seas, and satellites. Air & space, v. 2, Feb.-Mar. 1988: 42-47.

"Satellite imagery has revealed new features in the ocean, features that are too large and change too quickly to be detected easily from ships. Moreover, by providing vast amounts of data collected at regular, frequent intervals, satellites have allowed oceanographers to study already-known features in greater detail than previously possible."

Lunan, Duncan.

Man and the planets: the resources of the solar system. Bath, Ashgrove Press, 1983. 306 p.

Lunzer, Francesca.

Space business on the rise. High technology business, v. 8, July 1988: 43-46.

Describes the growing efforts to shift space research projects from the government to private industry. Also describes programs in West Germany, China and the Soviet Union that are ready to place clients' experiments in orbit.

Macauley, Molly K. Portney, Paul R.

Property rights in orbit. Regulation, v. 8, July-Aug. 1984: 14-18, 51-52.

Explains the geostationary arc (the orbit in space most suited for communications satellites) and describes how the FCC divides the U.S. portion of the arc among commercial users. Argues that a fairer system would be to lease arc spaces.

Making America more competitive: a platform for global economic success. Edited by Edward L. Hudgins. Washington, Heritage Foundation, 1987. 84 p.

Suggests an eight-plank program designed to increase the nation's standard of living while reducing the costs of goods and services in a globalized economy. Focuses on taxing and spending policies, government deregulation, space research, the banking industry, foreign trade issues, antitrust barriers, education reform, and labor policy.

Manber, Jeffrey K.

NASA's nervous customers. Across the Board, v. 23, Jan. 1986: 14-17.

"The forecasts of widespread industrial reliance on the shuttle for access to space have been forgotten, and space officials are digging in for a long battle convincing industry that space offers opportunities for profit not possible on the ground."

Maran, Stephen P.

Roadside service: the right stuff for space clunkers. Smithsonian, v. 16, Aug. 1985: 96-100, 102, 104.

Relates developments in repair and servicing of disabled spacecraft by U.S. astronauts. Describes plans to increase this capability, including design of a future Orbital Maneuvering Vehicle (OMV) which would be remotely controlled from the ground or from a space station.

Marsh, Peter.

Scientists gain a foothold in space. New scientist, v. 99, Sept. 22, 1983: 874-879.

Notes that the scientific community is divided over the probable benefits of Spacelab.

Marshall, Eliot.

Space stations in lobbyland. Air & space, v. 3, Dec. 1988-Jan. 1989: 54-61.

Recounts how the Industrial Space Facility, and the space station, got caught up in the Federal budget process.

Marshall, Harry R., Jr.

Commercialization of outer space. Dept. of State bulletin, v. 85, Jan. 1985: 35-39.

In this address before the International Astronautical Federation and the International Institute of Space Law, the Deputy Assistant Secretary for Oceans and International Environmental and Scientific Affairs expands actions that the government can take to promote the commercialization of space.

U.S. space programs: cooperation and competition from Europe. Dept. of State bulletin, v. 85, Sept. 1985: 83-87.

"Address before the Space Business Roundtable in Houston, Texas, on April 17, 1985. Mr. Marshall is Principal Deputy Assistant Secretary for Oceans and International Environmental and Scientific Affairs." Discusses the U.S. space program--where it is today and directions for the next few years.

Marth, Del.

Have rocket, will rent. Nation's business, v. 71, Aug. 1983: 32-35.

"American rockets that can be used only once, like the Titan, were to be phased out of the space program but may get a reprieve because of their potential for carrying commercial payloads."

Martin, Anthony R.

Space resources and the limits to growth. Journal of the British Interplanetary Society, v. 38, June 1985: 243-252.

States that there is no reason for the Earth to remain a closed system. Traces the possible impact which the exploitation of space resources could have on the Earth's population and standard of living over the next 500 years.

Materials processing in space. Edited by Bonnie J. Dunbar; associate editor, Esther Lense. Columbus, Ohio, American Ceramic Society, 1983. 343 p.

Mathematica, inc., Princeton, N.J.

Quantifying the benefits to the national economy from secondary applications of NASA technology--executive summary. Washington, 1976. 10 p.

"NASA CR-2674"

Report indicates that "operational methods can be developed for estimating the secondary benefits of mission oriented NASA R&D. Moreover "secondary benefits attributable to NASA's R&D programs may be impressively large." For example, a study of four examples indicates $7 billion in benefits is more than twice NASA's present yearly budget.

Matlack, Carol.
Landsat's slow death. National journal, v. 19, July 25, 1987: 1903-1905.
"The Administration broke its promise to pay for additional satellites, and even if it makes good, that may not be enough to save the heralded privatization venture."

Stalled at the station. National journal, v. 20, Mar. 26, 1988: 803-806.

Maule, R. William.
Satellite marketing under scrutiny. Communications and the law, v. 10, Aug. 1988: 17-25.
Describes the issues under investigation, and the participants (satellite retailers, satellite services, the public, and business and industry) affected by possible changes in telecommunications policy regarding satellite distribution, procurement of programming, and the control of media distribution channels.

May, G. Lynwood.
China advances in space. Spaceflight, v. 30, Nov. 1988: 428-433.
Reports on the Chinese Space Industry which has become a competitor in commercial space programs. Also looks at China's space capabilities.

McCain, Harry G.
NASA's first dexterous space robot. Aerospace America, v. 28, Feb. 1990: 12-16, 18, 20-24, 30.
Reports on the Flight Telerobotic Servicer (FTS), "a robotic device that can be teleoperated under the constant command of a human operator or run by itself under human supervision. Plans call for the FTS to assist the astronauts in the assembly, maintenance, servicing, and inspection of Space Station Freedom."

McLearn, Donald C.
Why drugs will be made in space. FDA consumer, v. 17, Nov. 1983: 19-23.
Describes the manufacturing technique called continuous flow electrophoresis which separates materials in solution by subjecting them to an electrical field and how this process, when used in space, can produce great quantities of materials such as enzymes, hormones and proteins for use in drugs.

Menter, Martin.
Commercial participation in space activities. Journal of space law, v. 9, spring-fall 1981: 53-68.
This article examines the impact of space treaties on the commercialization of space.

The Meteorological satellite: overview of 25 years of operation. Science, v. 231, Jan. 31, 1986: 455-462.
"The first weather satellite was launched on 1 April 1960. In the 25 years since, weather satellites have contributed to improved weather analyses and forecasts worldwide. As a maturing component of a global observing system, the meteorological satellite promises even greater financial benefits and a higher quality of life to mankind."

Miller, Rene H., and others.
Men or machines to build in space? Astronautics & aeronautics, v. 18, Oct. 1980: 52-59.
"Outline some the factors influencing the economics of exploiting space. [The authors] use the satellite power system (SPS) as an example, since it addresses a problem of great urgency--tapping our main renewable energy resource, the Sun."

Miller, Russell.
America's space entrepreneurs: what's up in the satellite business? Management review, v. 74, July 1985: 19-23.
Reviews the current commercial applications of communications satellites. Although numerous companies have developed a range of services using satellites, for most of them profits are still in the future.

Mordoff, Keith.
ELV makers gear for production restart. Commercial space, v. 2, spring 1986: 44-47.
"A new national launch policy is developing that will leave room for a mixed fleet of ELVs and space shuttles. Such a policy is being advocated strongly by some NASA officials, while others see expendables relieving the shuttle launch burden as only a short-term solution."

Morrison, David C.
Beyond the blue yonder. National journal, v. 20, Mar. 26, 1988: 798-802.

National Academy of Public Administration.
Encouraging business ventures in space technology; group report. Washington, The Academy, 1983. 96 p.
Prepared by a panel of the National Academy of Public Administration.

National benefits of aerospace exports. Washington, Aerospace Industries Association of America, 1983. 15 p.
Contents.--World trade environment and the U.S. trade position.--The structure and future of foreign trade in the aerospace sector.--The benefits of the aircraft industry to the U.S. economy.

National Research Council (U.S.). Committee on Advanced Space Technology.
Space technology to meet future needs. Washington, National Academy Press, 1987. 171 p.
This report, requested by NASA. examines the status of the technology base in advanced space research and technology from the perspective of future needs in space sciences, commercial applications, military needs, and manned exploration. Concludes that the advanced space research and technology program continues to be seriously underfunded and that "little has been done to enhance or develop the basic technologies that will enable future missions or provide the nation with a variety of options for the space program."

National Research Council (U.S.). Committee on Industrial Applications of the Microgravity Environment.
Industrial applications of the microgravity environment. Washington, National Academy Press, 1988. 55 p.
Reviews the current interest in materials processing in space and provides an assessment of the potential for technology transfer to U.S. industries.

National Research Council (U.S.) Space Applications Board.
Practical applications of space systems: a study, by the Space Applications Board of the Assembly of Engineering, National Research Council. Washington, National Academy of Sciences; available from Space Applications Board, National Research Council, 1975. 67 p.

Newkirk, Roland W. Ertel, Ivan D. Brooks, Courtney G.
Skylab: a chronology. Washington, Scientific and Technical Information Office, National Aeronautics and Space Administration for sale by the Supt. of Docs., G.P.O., 1977 [i.e. 1978] 458 p. (NASA SP-4011) (NASA history series)
Chronology relates the history, background, and missions of Skylab project through the launch of Skylab 4 on November 16, 1973.

Nichols, Robert G.
The winged horse. Ad astra, v. 1, Feb. 1989: 32-36.
Describes Pegasus, an air-launched, unmanned launch vehicle capable of placing small payloads in orbit at a cheaper price than ground-launched boosters.

Nimroody, Rosy.
Star Wars: the economic fallout. Cambridge, Mass., Ballinger Pub. Co., 1988. 234 p.
Partial contents.--What price strategic defense?--The race for contracts.--The top ten SDI contractors.--Targeting academia.--The pork barrel: who pays?--Technological rennaissance or brain drain?

Norton, D. J.
The commercial development of space. College Station, Tex., Center for Education and Research in Free Enterprise, Texas A&M University, 1987. 46 p. (Series on public issues; no. 27)

O'Brien, John E.
Allocation of risk and the commercial use of outer space. Federal Bar news & journal, v. 33, Apr. 1986: 169-172, 176.

The author, General Counsel of NASA, reviews the history of NASA's commercial agreements with private industry and describes several contractural devices used by NASA. States that the most controversial area has been the allocation of risks between NASA and its customers.

O'Leary, Brian.
The fertile stars. 1st ed. New York, Everest House, 1981. 132 p.

O'Neill, Gerard K. Driggers, Gerald. O'Leary, Brian.
New routes to manufacturing in space. Astronautics & aeronautics, v. 18, Oct. 1980: 46-51.

Contend that "because of energy costs it makes sense to use lunar materials for the construction of products needed in space. Less than a twentieth of the energy to bring a ton to orbit from the Earth will bring it there from the Moon."

Oceanography from space: a research strategy for the decade 1985-1995. Part 2: proposed measurements and mission, March 1985. Prepared by the Satellite Planning Committee of Joint Oceanographic Institutions Incorporated. Washington, The Institutions, 1985. 32 p.

States that there is an immediate need for a better understanding of the oceans and their role in the ocean-atmosphere-biosphere system. Asserts that satellite data are the key to measurement of global change. Recommends missions and measurements to provide the needed data.

Organization for Economic Co-operation and Development. The space industry: trade related issues. Paris, OECD, 1985. 92 p.

"The space products industry is entering a new phase of its development, characterised by broader commercialisation of products and related services, the enlargement of the supplier base, and sharper competition. The present report analyses space market trends, underlines the importance of scientific, technological and industrial cooperation between countries and between firms, and emphasizes the role of governmental policies with a specific focus on their trade impact."

Osborne, David.
Business in space. Atlantic monthly, v. 255, May 1985: 45-53, 56-58.

Examines the U.S. space program and the Reagan Administration's plans to encourage business enterprise in space by turning over as much as possible of the infrastructure to private corporations. Notes that at present the U.S. has a lead in the commercialization of space, but "the Europeans, Soviets, and Japanese are in the race, and in some areas they are ahead of us."

Pardoe, G. K. C.
The industrialisation of space. Journal of the British Interplanetary Society, v. 33, May 1980: 195-200.

Examines the use of outer space for communication, power, research and material processing.

Parkinson, R. C.
The future of launch vehicles. Space policy, v. 1, May 1985: 202-204.

"This article traces the development of satellite launch vehicles from the derivatives of long-range ballistic missiles to the current Ariane and Space Shuttle programmes. Looking to the next generation of launchers, the author outlines current thinking on reusable vehicles, focusing particularly on the British Aerospace/Rolls Royce HOTOL concept."

The potential market for a low cost launch vehicle, by R. C Parkinson and C. M. Hempsell. Journal of the British Interplanetary Society, v. 37, Feb. 1984: 51-54.

"The introduction of a launch vehicle with costs well below the current Shuttle and Ariane costs will significantly expand the launch vehicle market. An important factor in the feasibility of such a low cost launcher is the recovery of the substantial development costs, and it is argued that the expanded market will guarantee this payback."

Paul, Gunter.

The satellite spin-off: the achievements of space flight. Translated by Alan and Barbara Lacy. Washington, R. B. Luce, 1975. 272 p.

Peebles, Curtis.

A ticket to space. Spaceflight, v. 21, Mar. 3, 1979: 113-114.

Describes the development of a private manned space flight program of Robert Truax the former director of the Advanced Development Division of Aerojet General Corporation.

Pitts, William P.

Private firms want to help launch U.S. commercialization of space. National journal, v. 17, Jan. 26, 1985: 211-213.

"U.S. rocket launcher manufacturers say they can't compete with the subsidized NASA shuttle and European launcher. They are looking to the President for help."

The Political economy of outer space. American economic review, v. 76, May 1986: 269-284.

Contents.--Government R&D programs for commercializing space, by Linda R. Cohen and Roger G. Noll.--Incentive compatible space station pricing, by John O. Ledyard.--Out of space? Regulation and technical change in communications satellites, by Molly K. Macauley.

Pospisil, Milan.

Space power stations. OPEC bulletin, v. 13, Dec. 1982-Jan. 1983: 49-54.

"SPSs [space power station] are a promising and inexhaustible source of clean energy, but their development will require investment in energy and time. If the work proceeds satisfactorily, they could supply about one third of the world's demand for electricity by the middle of the next century."

Prehoda, Robert W.

The third industrial revolution. Futurist, v. 10, Apr. 1976: 91-92, 94-96.

Many of the environmental crises facing earth can be solved by the development of space industry, says a noted space expert. Raw materials can be obtained from the moon and from the asteroid belt. Future space transportation systems will allow the shipment of refined metals or finished products to the earth's surface at a reasonable cost."

President's Private Sector Survey on Cost Control (U.S.)

Report on privatization. Approved by the Subcommittee for the full Executive Committee, spring-fall 1983. Washington, The Survey, 1983. 209.

Partial contents.--Power marketing administrations.--Privatization of National Space Transportation System.--Veterans Administration: hospital management.--Commisary management.--Transfer of authority of metropolitan Washington airports.--Federal vehicle fleet management.--Privatizing selected Coast Guard services.--Social Security Administration: automated data processing.

Princeton/SSI Conference on Space Manufacturing (6th: 1983: Princeton University)

Space manufacturing, 1983: proceedings of a conference held May 9-12, 1983 at Princeton University, New Jersey. Edited by James D. Burke, April S. Whitt. San Diego, Calif., Published for the American Astronautical Society by Univelt, 1983. 478 p. (Advances in the astronautical sciences, 0065-3438 (corrected); v. 53)

Proceedings of a symposium on space communications research and development, Washington, National Academy Press, 1988. 330 p.

Studies policy issues, and possible future requirements for research and development in space communications. Major topics for discussion included: Federal presence in civil satellite communications technology development, current space communications technologies, areas of competition, regulations regarding space communications, role of the private sector and current investments in research.

Pross, Mark A.

The National Aero-space Plane. GAO journal, no. 4, winter 1988-89: 54-59.
Describes the National Aero-Space Plane Program and its goal "to develop and then demonstrate in a manned experimental flight vehicle--the X-30--the technologies necessary for future operational hypersonic airplanes and/or single-stage-to-orbit space launch vehicles that could deliver payloads into orbit more quickly, reliably, and inexpensively than today's space shuttle."

Reducing launch operations costs: new technologies and practices. Washington, Office of Technology Assessment, for sale by the Supt. of Docs., G.P.O., 1988. 94 p.

Discusses the issues of launch operations and how the use of advanced technologies and improved management techniques could reduce the costs of launching payloads.

Research Triangle Institute. Center for Systems Engineering. Florida Office.

Final baseline assessment: Eastern Space and Missile Center (ESMC). Washington, U.S. Department of Transportation. Office of Commercial Space Transportation, 1988. 92 p.

"RTI/4028/01-01F"

"Prepared under contract no. DTR-57-87-C-00116"

"The purpose of the study was to establish a baseline upon which OCST [Office of Commercial Space Transportation] could asses whether or not a commercial launch proposal is safe."

Ritholz, Andrew.

International and domestic regulation of private launching ventures. Stanford journal of international law, v. 20, spring 1984: 135-172.

"As demand for space travel has increased, so has the supply of space transportation services. Space is no longer the exclusive realm of NASA. Private launching ventures (PLVs) have developed to meet the increasing demand for space transportation services. This article explores the impact of PLVs and offers suggestions for regulating them in accordance with international law and national interests."

Robinson, George S.

Space law, space war and space exploitation. Journal of social and political studies, v. 5, fall 1980: 163-178.

Assesses how current space law will effect long-term private risk capital investment in space exploitation.

Who owns the moon? Foreign Service journal, v. 58, July-Aug. 1981: 22-25.

"In the evolution of space law, too many nations and people believed in an effective and successful ambience of cooperation for peaceful purposes in near- and deep-space activities. It distracted some of the decision-makers from proper considerations of the true military, economic, political, and ideological motivations of the primary space-law negotiators."

Saito, Shigebumi.

Japan's space policy. Space policy, v. 5, Aug. 1989: 193-200.

"Describes the formation of the Space Activities Commission as Japan's primary policy-making body, and of the National Space Development Agency, which oversees the development of space technology. The fundamental guidelines governing space activities are explained, and a detailed breakdown is given of projects agreed for the coming years."

Scheraga, Joel D.
Establishing property rights in outer space. Cato journal, v. 6, winter 1987: 889-903.

"The issue addressed in this paper is the allocation of the limited and desirable physical locations in outher space for geosynchronous satellites. How will these scarce resources be allocated? Can they be efficiently allocated? If peaceful and efficient coexistence in space is to prevail, then the creation and enforcement of property rights is inevitable."

Schlafly, H. J. Button, R. E. Wormington, B. L.
The initial growth and expanding opportunities of U.S. domestic satellite service. [Washington] U.S. National Telecommunications and Information Administration, 1979. 149 p.

"This report charts the growth of U.S. Domestic Satellite Communications during the first years of earth terminal proliferation with emphasis on the compatibility of satellite and cable as a total communications system."

Sheahen, Thomas P.
Space-born materials: how practical are they? Materials engineering, v. 107, Aug. 1987: 25-31.

This article questions whether materials processing in space is practical, discusses how materials are affected in orbit conditions, and presents guidelines for evaluating the economic feasibility of space processing.

Should we make products on the moon? Astronautics & aeronautics, v. 21, June 1983: 80-85.

"By the turn of the century, just a good development cycle away, commercial needs for large amounts of certain materials in Earth orbit may justify producing them on the Moon."

Smith, Bruce A.
Widespread civil uses envisioned for satellite navigation system. Commercial space, v. 1, spring 1985: 27-29.

"Applications for commercial navigation devices to receive signals from the Defense Dept.'s Navstar global positioning system (GPS) are expected to range from trucks and emergency vehicles to pleasure boats and commercial aircraft when the full constellation of eighteen Navstar statellites has been placed in orbit later this decade."

Smith, Delbert D.
The Moon treaty and private enterprise. Astronautics & aeronautics, v. 18, Jan. 1980: 62-65.

Advocates that the U.S. should protect its interests by clarifying "use" and "exploitation" in the U.N.'s proposed Moon treaty.

Smith, Gordon A.
Space commercialization. Report prepared by the Subcommittee on Space Science and Applications transmitted to the Committee on Science and Technology, U.S. House of Representatives, Ninety-eighth Congress, first session. Washington, G.P.O, 1983. 35 p.

Smith, Marcia S.
Satellite solar power stations: boon or boondoggle? Congressional Research Service review, Dec. 1981: 28-31.

Examines the costs and potential environmental impacts of a satellite solar power station.

Smith, Marcia S. Gravelle, Jane G. Whiteman, David L.
Insurance and the commercialization of space. Washington, G.P.O., 1985. 43 p. (Print, Senate, 99th Congress, 1st session, committee print S. Prt. 99-16)

Prepared for the committee on Commerce, Science, and Transportation, United States Senate.

Space business: new realities. Aviation week & space technology, v. 129, Dec. 19, 1988: 34-97 passim (35 p.)

Contents.--Commercial space ventures face harsh market realities, by Craig Covault.--Space business firm offer wide range of goods, services.--Most investors shun high-risk commercial space ventures, by Nicholas C. Kernstock.--Commercial remote sensing satellites generate debate, foreign competition, by Christopher P. Fotos.--Space-grown protein crystals will aid drug research.--3M moves into new research phase with polymer experiment on shuttle.--Small space service firms do well but large ventures find tough going, by Theresa M. Foley.--University centers program expands industry interest in space research, by Michael Mecham.--Near-term launch market looks bright, but questions remain on future prospects, by Michael A. Dornheim.--Small-payload launch companies struggle to define their market, by William B. Scott.--Strong orders signal end of slump for communications satellite market.--Mobile satellite communications firms expect strong market growth in 1990s, by Bruce D. Nordwall.--Soviet Union to broaden commmercial space activities, by Jeffrey M. Lenorovitz.--Europe building its own space business presence, by Keith F. Mordoff.

Space industrialization. Edited by Brian O'Leary. Boca Raton, Fla., CRC Press, c1982-. v. 1

Space industrialization opportunities, edited by Camille M. Jernigan and Elizabeth Pentecost. Park Ridge, N.J., Noyes Publications, 1985. 601 p.

Space industry international: markets, companies, statistics, and personnel. Editor, Geoffrey K.C. Pardoe. Harlow, Essex, UK, Longman; Detroit, MI, Distributed exclusively in the USA, its possessions, and Canada by Gale Research Co., 1987. 353 p. (Companion for industry)

Space stations. Journal of the British Interplanetary Society, v. 40, Jan. 1987: whole issue (48 p.)

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Boyd-Carpenter, T. P. J.

Will SDI help? A military view. In RUSI and Brassey's Defence Yearbook, 1987. London; New York, Brassey's Defence Publishers, 1987. p. 51-62.

Personal reflections on the subject of SDI to illuminate some of the strategic criteria if a definitive answer is to be forthcoming.

Broad, William J.

A fatal flaw in the concept of space war. Science, v. 215, Mar. 1982: 1372-1374.

A poor start for the militarization of space. Science, v. 216, May 1982: 599-602.

Claims that "the rush to build a $1.4-billion command post has resulted in waste, fragmentation, and a computer system that will be obsolete the day it is switched on.'

Star warriors: a penetrating look into the lives of the young scientists behind our space age weaponry. New York, Simon and Schuster, c1985. 245 p.

Brown, George E., Jr.

Pentagon usurps civilian space program. Bulletin of the atomic scientists, v. 43, Nov. 1987: 26-31.

"The growing military domination of space budgets, resources, and personnel has forced NASA to make way for the Reagan administration's vision of space as a battleground rather than an arena for exploration and cooperation." Reviews activities which show how the United States military space effort has expanded.

Brown, Harold. Feld, Bernard. Jastrow, Robert. Garwin, Richard.

The space shuttle and defense. New York, WNET/Thirteen, 1981. 8 p.

The MacNeil/Lehrer Report, Apr. 13, 1981.

Televised interview with "Harold Brown, former Defense Secretary; Bernard Feld, physicist; Robert Jastrow, NASA; Richard Garwin, physicist."

"The military possibilities of the space shuttle."

Brown, William W.

The balance of power in outer space. Parameters, v. 7, no. 3, 1977: 8-15.

Bruce-Briggs, B.

A catechism of strategic defense. National review, v. 36, Oct. 5, 1984: 26, 28, 30-32, 34.

"A primer on strategic vocabulary and thought," of strategic defense and its relevant points: effectiveness costs, etc.

Brzezinski, Zbigniew.

Defense in space is not 'Star Wars,' by Zbigniew Brzezinski, Robert Jastrow, and Max M. Kampelman. New York times magazine, Jan. 27, 1985: 28-29, 46, 51.

"Deflecting a nuclear attack, the authors argue, should not be seen as science fiction."

A Star Wars solution: how to break the arms control impasse. New Republic, v. 193, July 8, 1985: 16-18.

Bulkeley, Rip. Spinardi, Grapham.

Space weapons: deterrence or delusion. Totowa, N.J., Barnes & Noble Books, 1986. 378 p.

Bunn, George.

Open skies for missile killers? Crossing the legal boundaries of space. Arms control today, v. 17, May 1987: 14-16.

Discusses the status of missile-killer satellites (SDI) under international law.

Burant, Stephen R.
Soviet perspectives on the legal regime in outer space: the problem of space demilitarization. Studies in comparative communism, v. 19, autumn-winter 1986: 161-175.

Burrows, William E.
Deep black: space espionage and national security. 1st ed. New York, Random House, 1986. 401 p.

Burton, Andrew D.
Daggers in the air: anti-satellite weapons and international law. Fletcher forum, v. 2, winter 1988: 143-162.

"Arms control issues, the Strategic Defense Initiative and recent developments in military satellite technology make space law particularly relevant to international security issues today. . . . Analyzes the relationship between space law and anti-satellite weapons. . . . [discusses anti-satellite weapons] within the broader context of arms control negotiations and makes several observations about the future of space weapons and law."

Cady, Steven E.
Beam weapons in space. Air University review, v. 33, May-June 1982: 33-39.

Discusses the development and deployment of directed-energy weapons in space.

Callaham, Michael B.
Laser weapons. IEEE spectrum, v. 19, Mar. 1982: 51-55.

"Laser weapons will never be weapons of mass destruction. The largest carbon-dioxide laser ever built produces pulses of only 10-kilojoule energy, the muzzle energy of 20 .45-caliber bullets. However, a prolonged sequence of such pulses, properly focused, could damage satellites at 100 kilometers or more. Laser weapons have been described as 'ice pick' weapons: they can neutralize a variety of targets but only if wielded with great finesse."

Canan, James W.
War in space. 1st ed. New York, Harper & Row, c1982. 186 p.

Carpenter, Ted Galen.
Two cheers for SDI. In Assessing the Reagan years. Edited by David Boaz. Washington, Cato Institute, c1988. p. 113-123.

Argues that though the opponents of the Strategic Defense Initiative (SDI) are probably correct in asserting that an impenetrable shield is not technologically feasible, SDI can provide protection from an accidental launch, a limited attack, or attack from radical future nuclear powers. Also argues that SDI would increase the U.S.'s foreign policy options by completing "the process of making allies dispensible."

Carter, Ashton B.
Satellites and anti-satellites: the limits of the possible. International security, v. 10, spring 1986: 46-98.

"One purpose of this article is to provide the background to non-technical readers . . . . A second purpose of this article is to identify the technical and military factors that should inform a mature policy debate . . . . Skepticism about the value of ASAT arms control, is the third purpose of this article."

Chalfont, Arthur Gwynne Jones, Baron.
SDI in context. United States Naval Institute proceedings, v. 112, Apr. 1986: 70, 72-76.

"The semi-hysterical, topsy-turvy rhetoric that has greeted the unveiling of the Strategic Defense Initiative cannot obscure the fact that space is already part of our strategic thinking--and will inevitably continue to remain so."

Chandler, William U.
Assessing SDI. In State of the world 1988. Edited by Linda Starke. New York; London, W. W. Norton & Company, 1988. p. 137-150.

"The Reagan vision of perfect defense is an illusion. The technology is too remote, the mission too complex, the possibilities for defeating or circumventing ballistic missile defenses too numerous."

Chappell, Bill.

The need for a Strategic Defense Initiative: a peace strong enough to deter war. Vital speeches, v. 51, July 1, 1985: 546-548.

"Delivered to the United States Congressional Board of the American Security Council Foundation, Washington, D.C., June 4, 1985."

Charles, Daniel.

Bringing SDI down to earth. Science, v. 237, Aug. 14, 1987: 713-715.

In 1986 Congress voted $300-million toward development of a "smart weapons" sysem using "sophisticated sensors and tiny high-speed computers to seek out and destroy targets without aid of human eye or brain." Critics of this system and its counterpoint, SDI, say it will require major technological leaps, will be "unduly expensive and will not work."

Charlton, Michael.

From deterrence to defense: the inside story of strategic policy. Cambridge, Mass., Harvard University Press, 1987. 154 p.

"This Star Wars history chronicles the American strategic debate over the last two decades through no-holds-barred interviews with the men whose views and advice have directly influenced crucial nuclear decisions."

Christol, Carl Q.

Arms control and disarmament in space: the rough road to Vienna 1984: parts I and II. Space policy, v. 1, Feb. 1985: 28-48; Aug.: 263-288.

"This article examines the international legal and diplomatic questions relating to arms control and disarmament, focusing on space-based activities. These relate importantly to the development of anti-satellite satellites (ASATs) and ballistic missile defence systems (BMDs)."

Claxton, Bernard D.

Traditional American military doctrine and SDI. Defense analysis, v. 4, Dec. 1988: 347-359.

Cohen, Samuel.

The Strategic Defense Initiative: a shield, not a sword. Washington, Heritage Foundation, 1988. 8, 2 p. (Backgrounder no. 628)

Contends that "the Strategic Defense Initiative (SDI) could not be used as an offensive weapon, as the Soviet Union and American SDI critics have claimed."

Coker, David S.

'High Frontier': bold new strategy for national defense. Human events, v. 42, May 22, 1982: 11, 15.

"Amidst the heated debate over the future of U.S. nuclear weapons policy, Project High Frontier calls for the use of outer-space weaponry to defend against Soviet nuclear attack and the adoption of a new strategic military doctrine."

Cole, Stephen V.

Preparing for war in space. Review of the news, v. 17, July 22, 1981: 39, 41, 43, 45, 47, 49, 51, 53, 55, 57-58.

Points to the possibility of space war between the US and the Soviet Union, and describes the space battlefield and weapons.

Collalto, Carlo.

The militarization of outer space: European perspectives. International spectator, v. 19, July-Dec. 1984: 155-161.

"Presently the projects have not gone beyond the research stage. It can be assumed, however that unless an effective arms control process takes place, outer space will become the military sector into which the greatest efforts and the newest technologies will be channelled in the next decades. . . . The relatively modest efforts made by Europeans in the field of military space projects have reinforced their basically skeptical stance on the effectiveness and the necessity for these devices and has led them to favor arms control initiatives aimed at preventing an arms race in outer space."

Collins, John M.
Military space forces: the next 50 years. 1st ed. Washington, Pergamon-Brassey's, 1989. 236 p. (Future warfare series; vol. 4)
An overview that opens with an area analysis, then covers command arrangements, strategies, tactics, forces, research and development, and U.S.-Soviet capabilities.

Collins, William, Jr. Leonard, Jonathan.
The Star Wars offense. Harvard magazine, v. 91, Jan.-Feb. 1989: 20-25.
Argues that "Star Wars weapons are not really defensive. They harm rather than help our security."

Consequences of creating a space-based anti-missile system using directed-energy weapons. Defense science 2003+, v. 4, Dec. 1985-Jan. 1986: 47-53, 63-68.
"This report was prepared by the Working Group of the Committee of Soviet Scientists for Peace Against Nuclear Threat. The report originally was published by the Institute of Space Research at the USSR Academy of Sciences." Contends that "the effectiveness of a space anti-missile system based on X-ray lasers is open to serious doubt."

Cooper, Henry F.
Anti-satellite systems and arms control: lessons from the past. Strategic review, v. 17, spring 1989: 40-48.
"After a decade of research, development and testing, costing over $1.5 billion, the U.S. F-15 ASAT program was cancelled in 1988. The history illustrates the disastrous consequences of not achieving bipartisan support for important defense programs where technology and national security policy are in a high state of flux."

Cooper, Robert S.
No sanctuary: a defense perspective on space. Issues in science and technology, v. 2, spring 1986: 38-45.
The author, the former director of the Defense Department's Defense Advanced Research Projects Agency argues that the military use of space has been "rational and logical and says that attempts to make space a 'sanctuary' from military activity are not realistic or useful."

Dahlitz, Julie.
ASAT and related weapons: proposals for the prevention of an arms race in outer space. Oslo, International Peace Research Institute, [1983] 20 l. (PRIO report, 0333-483X; 21/83)

The option of Star Wars: meaning and consequences. Bulletin of peace proposals, v. 16, no. 2, 1985: 99-104.

Dash, Ernie R. Meyer, Walter D.
The meteorological satellite: an invaluable tool for the military decision-maker. Air University review, v. 29, Mar.-Apr. 1978: 13-24.
"Meteorological satellites provide. . . military decision-makers with large area observations or depictions of the existing weather. This imagery is especially valuable . . . and is indispensable . . . during times of conflict."

Deudney, Daniel.
Forging missiles into spaceships. World policy journal, v. 2, spring 1985: 271-303.
"This article sets forth a peace strategy for space cooperation. Its agenda calls for large-scale cooperation between the United States and the Soviet Union in the manned exploitation of deep space and multilateral efforts to secure earth by making better use of space technologies."

Unlocking space. Foreign policy, no. 53, winter 1983-1984: 91-113.
"Outer space is both the leverage point for the current superpower military competition and the point from which an alternative security order could be built . . . . With space technology the human species is playing with a fire of awesome potential for destruction and creation. Unless these technologies are used to secure the whole Earth, they may flare disastrously out of control."

Devereux, Tony.

Space defence: Europe must help itself. Defence attache, no. 4, 1986: 28, 30-31, 33-35.

"It may be argued that in space defence Europe is already doing for America all it can do and should do, in the form of contractual participation in SDI."

Diaz, Tom.

Strategic Defense Initiative. Washington times, Feb. 10, 1986: 1A, 5A; Feb. 11: 1A, 6A; Feb. 12: 1A, 8A; Feb. 13, 1A, 16A; Feb. 14: 1A, 16A.

Contents.--Soviets lead in laser beam weapons for space shield.--Soviet space age weaponry is central to U.S. research.--The accidental launch: atomic age nightmare.--Building of a 'star wars' system poses high drama for scientists.--If nothing else, 'star wars' got Soviets to resume talks.

Dillingham, Wayne E.

The legal status of United States Air Force Women in front-line space combat operations. Minerva (Arlington, Va.), v. 7, fall-winter 1989: 41-56.

"There is an ever-increasing likelihood that, in future armed conflicts involving the United States, American military women will be directly engaged in front-line combat operations . . . . Yet, with all of this heated discussion as to whether American military women should be allowed to fight and die . . . one potential combat arena appears to have been overlooked in the debate: space."

Dimaggio, Cosmo.

The Strategic Defense Initiative: U.S. criteria and policy considerations. Congressional Research Service review, v. 7, May 1986: 14-16, 25-26.

Discusses the criteria of survivability, cost, and effectiveness which will be considered in the decision whether to proceed with full scale engineering development and deployment of an SDI system. Includes research guide, Finding Information on the Strategic Defense Initiative, by B. F. Mangan.

Din, Allan M.

Stopping the arms race in outer space. Journal of peace research, v. 20, no. 3, 1983: 221-225.

"The militarization of outer space has been accelerating in recent years and is likely to reach a climax sometime during the second half of this decade. The advent of spacebased weapon systems is particularly disquieting and a consequence of such a development will be an increasing risk for triggering--either accidentally or intentionally--a nuclear war. Existing arms control treaties, like the ABM treaty, appear to offer a gradually diminishing protection against this growing military buildup and a special effort will be needed to stop the trend."

Dooling, Dave.

America shapes up for war in space. New scientist, v. 96, Nov. 11, 1982: 348-351. "Military officials are beginning to see space as a place where war may be fought, even though many people had hoped that the resources beyond the Earth's atmosphere could be kept peaceful by international agreement."

Dore, Isaak I.

International law and the preservation of the ocean space and outer space as zones of peace: progress and problems. Cornell international law journal, v. 15, winter 1982: 1-61.

Partial contents.--The politics of outer space: pertinent Soviet and American attitudes.--The military potential of outer space.--The emergence of treaty law with respect to the demilitarization of outer space.--Questions arising under the Outer Space Treaty.--Prospects for the future under the Outer Space Treaty.

Downey, Arthur J.

The emerging role of the US Army in space. Washington, National Defense University Press, for sale by the Supt. of Docs., G.P.O., 1985. 92 p. (National security affairs monograph)

Partial contents.--Space policy: goals and directions.--The present military roles and missions in space.--Military organization for space.--Technology, the future, and the impact on the Army.

Edelson, Edward.
Space weapons--the science behind the big debate. Popular science, v. 225, July 1984: 53-59, 100.

Assesses the probability of developing a space-based weapons system that could shield the U.S. from a nuclear missile attack.

Eisler, Steven.
Space wars: worlds and weapons. New York, Crescent Books, c1979. 96 p.

Elkin, Jerrold F. Fredericks, Brian.
Military implications of India's space program. Air University review, v. 34, May-June 1983: 56-63.

"There is no evidence to suggest that New Delhi is currently employing space program assets to satisfy defense requirements. It must be recognized, however, that many of the accomplishments of India's space scientists have direct military applicability."

Evans, David D. Gajewski, Ralph R.
Expanding role for autonomy in military space. Aerospace America, v. 23, Feb. 1985: 74-77.

"Autonomy means onboard, unmanned decision-making through use of computers and reprogrammable software, and the ability to accept human intervention."

The Fallacy of Star Wars. Edited by John Tirman. 1st ed. New York, Vintage Books, 1984. 293 p.

Based on studies conducted by the Union of Concerned Scientists; and co-chaired by Richard L. Garwin, Kurt Gottfried, and Henry W. Kendall; edited by John Tirman.

Felden, Marceau.
Space in the survival of Europe. Geopolitique, no. 6, spring-summer 1984: 29-41.

Fitzgerald, E. M.
The command of space. RUSI [Journal of the Royal United Services Institute for Defence] Studies, v. 126, Mar. 1981: 34-38.

"Despite the 1967 Outer Space Treaty which forbids the use of outer space for military purposes, inadequacies of our present nuclear weapon balance may compel the US and USSR to seek unique and more secure geopolitical footholds . . . For the superpowers, a single escapehatch may be a move to 'higher grounds.'"

Florig, H. Keith.
The future battlefield: a blast of gigawatts? IEEE spectrum, v. 25, Mar. 1988: 50-54.

Florini, Ann M.
The opening skies: third-party imaging satellites and U.S. security. International security, v. 13, fall 1988: 91-123.

"This paper provides a preliminary guide to the issues raised by the spread of military and civilian satellite imagery. It briefly outlines the existing and planned satellite systems; analyzes what they can see; discusses the implications of this new information source for U.S. national security in peacetime, crisis, and war; and proposes a series of policy options."

Foley, Theresa M.
SDI: billion-dollar opportunity. Commercial space, v. 2, spring 1986: 18-22.

Analyzes where the $6 billion awarded since 1983 for contracts in the Strategic Defense Initiative Program has gone. Lists universities and firms which have received contracts and shows which states have benefited most.

Franklin, H. Bruce.
War stars: the superweapon and the American imagination. New York, Oxford University Press, 1988. 256 p.

Friel, Patrick J.
U.S. ballistic missile defence technology: a technical overview. Comparative strategy, v. 4, no. 4, 1984: 319-347.

Provides a brief history of U.S. ballistic missile defense technology. Describes the technical performance characteristics of various ballistic missile defense concepts and technologies. Concludes "terminal defense of ICBM silos appears to be technically and economically feasible and could be deployed now. In addition, a ballistic missile defense of the entire United States, in which the sensors are space-based and the interceptors are deployed in the United States, is an attractive area of technology to be developed."

Garden, Group Captain.
Space: the military applications: today and tomorrow. In RUSI and Brassey's Defence Yearbook 1985. London; Washington, Brassey's Defence Publishers, 1985. p. 149-161.

The article looks "at the military applications of space today, and how they may be developed, and also at the proposals and possibilities for novel systems in the future."

Garthoff, Raymond L.
Banning the bomb in outer space. International security, v. 5, winter 1980-1981: 25-40.

"The 1963 UN Resolution and the 1967 Space Treaty have made a contribution, and perhaps a significant one, to a more stable and secure world," concludes the author.

Garwin, Richard L.
Antisatellite weapons, by Richard L. Garwin, Kurt Gottfried, and Donald L. Hafner. Scientific American, v. 250, June 1984: 45-55.

An SDI defense: a Maginot line in space. Center magazine, v. 20, Nov.-Dec. 1987: 45-53.

In this article and the dialog which follows, former Presidential advisor examines the SDI system and its effectiveness.

Gelb, Leslie H.
Weapons in space: how program and debate are moving ahead. New York times, Dec. 15, 1985: 1, 34; Dec. 16: A1, B12; Dec. 17: A1, A16.

Contents.--'Star Wars' advances: the plan vs. the reality.--Science showmanship: a deep 'Star Wars' rift.--'Star Wars' in strategy: the Russian response.

Giffen, Robert B.
U.S. space system survivability: strategic alternatives for the 1990s. Washington, National Defense University Press, 1982. 68 p. (National security affairs monograph series, 82-4)

"Colonel Robert B. Giffen, USAF, examines strategies to assure the survivability of US space systems. His analysis leads him to conclude that incorporating survivability into the initial design of a space system is essential. This includes deciding what capability must survive, and to what level of conflict it must endure. As the author points out, the largest obstacle to implementing survivability will be cost, which must be paid in the initial appropriation."

Glaeser, Frederick J.
Space: a new dimension in naval warfare. United States Naval Institute proceedings, v. 113, May 1987: 125-135.

"In examining the tactical implications of future space technology, this article avoids estimates of future U.S. or Soviet capabilities and focuses instead on what current research is making available and how such capabilities can affect naval warfare."

Goedhuis, D.
Some observations on the efforts to prevent a military escalation in outer space. Journal of space law, v. 10, spring 1982: 13-30.

Article concludes that "the world population as a whole is--to a very great extent--still in the dark regarding the immense effect which space developments are going to have on all human life. It is this lack of perception in the world of what is at stake in outer space which has an unfortunate effect on the aim of achieving arms limitations in this medium. Whereas one may be hopeful of the possibility of arriving at a ban on the testing of anti-satellite weapons, the chances of reaching a universal agreement on arms limitations in space on a broader scale, will--to a considerable degree--depends on a much more widespread public consciousness of the vital need to reach such an agreement."

Goldstein, Gary R.
The requirements for free electron laser space weapons: possible or prohibitive? Cambridge, Massachusetts Institute of Technology, 1987. 52 l. (Report no. 18)

Reviews the probability of the free electron laser (FEL) as a ground based laser system for the Strategic Defense Initiative Program. Concludes that a "ground based FEL weapon will require so many orders of magnitude improvement over the existing complex of performance capabilities that it is not a sensible direction of intense effort and expense."

Goure, Dan.
Space conflict strategies. Defense & foreign affairs, v. 9, Aug.-Sept. 1981: 15-17, 37-38.

Though weapons of mass destruction were banned from space by the 1967 Outer Space Treaty, author sees the superpower conflict leading to space-based weapons.

Graham, Daniel O.
High frontier. New York, T. Doherty Associates, Distributed by Pinnacle Books, c1983. 314 p.

Space: high frontier of security and free enterprise. Lincoln review, v. 6, spring 1986: 9-24.

Blacks and SDI, an introduction by Roy Innis.

Gupta, Rakesh.
US militarization in outer space. International studies, v. 22, Apr.-June 1985: 153-168.

Argues that "the US space programme as evolved over the last twenty-five years has shown a tendency towards militarization."

Hafner, Donald L.
Outer space arms control: unverified practices, unnatural acts? Survival, v. 25, Nov.-Dec. 1983: 242-248.

"In the decade from 1963 to 1973, the US and Soviet Union achieved important restrictions on military activities in outer space, including the Limited Test Ban Treaty, the Outer Space Treaty, and the Anti-Ballistic Missile (ABM) Treaty. In the decade since 1973, little more has been accomplished, despite the promise of the first rounds of negotiation in 1978-9 on limits for anti-satellite weapons (ASAT)."

Hamm, Manfred R. Weinrod, W. Bruce.
The transatlantic politics of strategic defense. Orbis, v. 29, winter 1986: 709-734.
Surveys European attitudes toward SDI and the impact of this new strategy on the NATO alliance. Concludes that "by providing a more solid foundation for allied security, SDI can strengthen NATO while it could also have a highly divisive effect on allied relations . . . . Whether the Alliance will survive these challenges may depend less on SDI's objective opportunities than on the way the allies cope with its multiple ramifications."

Hansen, Richard Earl.

Freedom of passage on the high seas of space. Strategic review, v. 5, fall 1977: 84-92.

"The time is at hand when it will be appropriate to apply the principle of freedom of the seas to space and the eventual need to defend that freedom of passage where challenged. The exercise of counterspace tactics to neutralize communications, early-warning or defensive systems would give a nation a strategic advantage to a conflict situation."

Harnly, Caroline D.

Space weapons. Compiled by Caroline D. Harnely and edited by David A. Tyckoson. Phoenix, Ariz., Oryx Press, 1985. 69 p. (Oryx science bibliographies; v. 2)

Hartman, Richard.

War in space. Electronic warfare/defense electronics, v. 10, Oct. 1978: 34-36, 38, 40, 42, 44, 46.

"Increasing US and Soviet military dependence on satellite-based systems ensures that battlefields of the future will extend to outer space."

Hartung, William. Nimroody, Rosy.

Star Wars: what price strategic defense? New York, Council on Economic Priorities, 1985. 6 p. (CEP publication N85-1)

Discusses economic implications of the scope and pace of the Strategic Defense Initiative (SDI) program.

Hecht, Jeff.

Beam weapons: the next arms race. New York, Plenum, 1984. 363 p.

Presents "a comprehensive, accurate, and balanced view of the technology behind the Strategic Defense Initiative (popularly called "Star Wars"), which may represent a significant step in the militarization of space."

Star wars--an astronomical bribe for scientists. New scientist, v. 106, June 20, 1985: 14-18.

"Officials of the star wars programme readily admit that they do not know what the research programme will come up with. But many scientists recognise that the programme will provide them with a ready source of funds. Will the momentum now building up prove unstoppable?"

Herres, Robert T.

The military use of space: the Soviet space program. Vital speeches of the day, v. 53, Nov. 15, 1986: 74-77.

"Taken together, already operational and future Soviet space capabilities are a cause for genuine concern . . . . If, on the other hand, we continue to compete, we must accept that military capabilities must be met with military capabilities. Nothing would be more dangerous or de-stabilizing than a situation in which the Soviets perceived a clear military advantage over us in any regime--land, sea, air or space. We must struggle not for superiority, but to retain a balance", argues Commander in Chief, U.S. Space Command and North American Aerospace Defense Command.

The High technologies and reducing the risk of war. Edited by H. Guyford Stever and Heinz R. Pagels. New York, New York Academy of Sciences, 1986. 167 p. (Annals of the New York Academy of Sciences; v. 489)

Hill, William A. Jr.

Permissible scope of military activity in outer space. Air Force law review, v. 24, no. 2, 1984: 157-175.

This article concludes that "earthly tensions, difficulty of treaty compliance verification, and the undeniable usefulness of satellites make it particularly inevitable that military activities in space will continue to expand. Existing treaty law and the current practice among space-capable nations demonstrate that military activities in space were not prohibited and actually preexisted the earliest space treaties. Those activities have been constrained very little by the relevant treaties as they developed."

Hobbs, David.
An illustrated guide to space warfare. New York, Prentice-Hall, c1986. 155 p.

Hochman, Sandra. Wong, Sybil.
Satellite spies: the frightening impact of a new technology: an investigation. Indianapolis, Bobbs-Merrill Co., c1976. 212 p.

Humble, Ronald D.
On the military use of space. RUSI [Journal of the Royal United Services Institute for Defence] Studies, v. 127, Sept. 1982: 38-45.

"This article proposes that the inherent military advantages afforded by the space . . . numerous . . . technological innovations . . . will promote the adoption of a primarily defensive space-based military strategy by the major powers during the next few decades."

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Space warfare in perspective. Air University review, v. 33, July-Aug. 1982: 81-86.

"Technological developments are necessitating the implementation by the United States and other Western nations of a cohesive, coordinated space doctrine that considers space in accordance with its true strategic value. Military decision-makers and planners must begin to think in such radical new terms if they are to utilize to the maximum this ultimate 'high ground' for the defense of the West."

Hunter, Maxwell.
The star warriors. Newsweek, v. 105, June 17, 1985: 34-38, 41-42, 45.

Looks at the weapons research needed to develop a "Star Wars" defense. Profiles scientists who are interested in developing such weapons.

Hunter, Robert E.
SDI: return to basics. Washington quarterly, v. 9, winter 1986: 155-167.

"As debate about SDI has developed during the past two and a half years and has become more intensely political, in both domestic and foreign terms, it is worth trying to create a basic benchmark of strategic analysis against which to measure particular proposals . . . Strategic theory provides the critical test--whether Reagan's original idea . . . should be pursued, or whether SDI should simply be foresworn."

Hylin, Carl F.
Stemming the arms race in outer space: suggested revisions of the Outer Space Treaty based on three successful arms control measures. California Western international law journal, v. 16, winter 1986: 118-137.

"This Comment is devoted to a discussion of the 1967 Outer Space Treaty. The discussion will include an examination of its peaceful purpose, different interpretations of this purpose, along with the goals and intentions of the two major parties in formulating the Treaty. Following the discussion of this peaceful purpose, the Treaty's arms control capacity will be analyzed."

Ince, Martin.
Space wars: a graphic guide. London, Camden Press, 1986. 171 p. (Graphic guides)

International co-operation in the peaceful uses of outer space. [New York] United Nations, 1978. 5 p. (United Nations. Document A/33/162)

At head of title: United Nations General Assembly.

International security dimensions of space. Edited by Uri Ra'anan and Robert L. Pfaltzgraff, Jr. Hamden, Conn., Archon Books, 1984. 324 p.

"A outgrowth of papers presented at the 11th annual conference of the International Security Studies Program of the Fletcher School of Law and Diplomacy, held at the Fletcher School's Cabot Center on April 27-29, 1982.

Jacky, Jonathan.
The "Star Wars" defense won't compute. Atlantic monthly, v. 255, June 1985: 18, 20, 22, 24, 26, 28-30.
Quotes Star Wars proponents who have acknowledged that the missile defense system will depend on computer control to launch weapons. Argues that the complexity of the software needed is far beyond anything available now and that if it is developed, it will be impossible to discover all the programming errors without prolonged experience in actual use.

Jasani, Bhupendra.
Arms race in outer space. Alternatives, v. 4, July 1978: 59-85.
"Since the dividing line between civilian and military technology has vanished, Man can use the same means for enriching life on Earth as for destroying all life. This paper details the types of satellites that have so far been launched, that are in an experimental stage and that are on the drawing board, and the uses to which they are being put and can be put. The total picture that emerges is frightening in the extreme."

Countdown to space war, by Bhupendra Jasani and Christopher Lee. London, Philadelphia; Taylor & Francis, 1984. 104 p.

The military use of outer space. In World armaments and disarmaments, SIPRI yearbook 1984. Philadelphia, Taylor & Francis, 1984. p. 351-378.
During the 25 years of the space age, outer space has remained free from the deployment of any weapons of mass destruction. Militarization of the outer space environment has continued nonetheless . . . . From 1958 to 1983, 2114 military-satellites range from navigation, meteorology and geodesy to reconnaissance and anti-satellite activities . . . . Some of the technical and arms-control aspects of developments in the field of ASAT and BMD as well as observations from space of conflict areas and military manoeuvres are briefly examined in this chapter."

Outer space--battlefield of the future? London, Taylor & Francis, 1978. 202 p.

Outer space being turned into a battlefield. Bulletin of peace proposals, v. 17, no. 1, 1986: 29-39.
"While anti-satellite (ASAT) weapons are not yet deployed in orbits around the Earth, we are on the verge of introducing such weapons into outer space under the quise of defensive systems. In this paper, three aspects (i.e. military satellites, ASAT weapons and defensive weapons) of the militarization of space are briefly described and its consequences are discussed."

Johnson, Nicholas L.
Soviet military strategy in space. London, James Pub. Co., c1987. 287 p.
Presents "a concise analysis of the past, present, and anticipated actions of the Soviet Union relating to the militarisation of space."

Jones, Rodney W. Hildreth, Steven A.
Star wars: down to earth, or gleam in the sky? Washington quarterly, v. 7, fall 1984: 104-111.
"Whatever technology paths are explored and future deployment choices made, arms control measures will be highly desirable . . . and in some respects positively necessary."

Kaku, Michio.
Wasting space: countdown to a first strike. Progressive, v. 47, June 1983: 19-22.
Discusses the frightening implications of space-based weapons.

Kane, Francis X. Meyer, S. C. Howe, James R.
How strategic defenses can prevent war. Washington, Heritage Foundation, 1988. 6 p. (National security record no. 114)
Presents "an unclassified summary of a classified study of the role of strategic defenses in preventing war, which was prepared for Rockwell International."

Karas, Thomas H.
The new high ground: systems and weapons of space age war. New York, Simon and Schuster, 1983. 224 p.

Karp, Aaron.
Space technology in the Third World. Space policy, v. 2, May 1986: 157-168.
Discusses the spread of older missile technology to the Third World and points to the danger that these nations will use satellite launch technology for military applications. Urges establishment of an International Missile Technology Regime to limit the transfer of space launch technology to nations in compliance with the Nuclear Non-Proliferation Treaty.

Koppes, Clayton R.
The militarization of the American space program: an historical perspective. Virginia quarterly review, v. 60, winter 1984: 1-20.
"The classical era of the American space program has come to an end. After a quarter century in which peaceful and scientific activities played the major role, the space program is veering toward domination by the military. The Reagan administration has given added impetus to this development in two important ways . . . . The purpose of this article is to sketch the direction of the space program of the 1980's and to analyze the historical developments that prepared the way for this ominous turn from science to a possible 'star war.'"

Lacouture, John E.
Space race. United States Naval Institute proceedings, v. 109, Feb. 1983: 51-57.

Langenberg, William H.
U.S. ASAT: whither now? Washington quarterly, v. 9, fall 1986: 101-116.

Larson, Joyce E. Bodie, William C.
The Intelligent layperson's guide to "Star Wars." New York, National Strategy Information Center, 1986. 59 p.
"16 questions & answers on strategic defense and space weaponry."

Laser weapons in space: policy and doctrine. Edited by Keith B. Payne. Boulder, Colo., Westview Press, 1983. 230 p. (A Westview replica edition)

Lee, Christopher.
War in space. London, H. Hamilton, 1986. 242 p.

Lupton, David E.
On space warfare: a space power doctrine. Maxwell Air Force Base, Ala., Air University Press, for sale by the Supt. of Docs., G.P.O., 1988. 149 p.
Partial contents.--Space power, space forces, and doctrine.--Space force characteristics.--Space doctrines.--The high-ground doctrine: strategic foresight or illusion?--The control school: historical analogy or fallacy?--Implementing a space power doctrine.

Macvey, John W.
Space weapons, space war. London, New English Library, 1982, c1979. 286 p.

Manno, Jack.
Arming the heavens: the hidden military agenda for space, 1945-1995. 1st ed. New York, Dodd, Mead & Co., 1984. 245 p.

Markoff, Marko G.
Disarmament and "peaceful purposes" provisions in the 1967 Outer Space Treaty. Journal of space law, v. 4, spring 1976: 3-32.
This article analyzes the arms control provisions of article 4 which deals with military activities in outer space.

May, Michael M.
Safeguarding our military space systems. Science, v. 232, Apr. 18, 1986: 336-340.
Discusses the vulnerability of military space systems, means of attacking military satellites, and methods of protecting them. States that the deployment of a strategic defense system would change the picture completely. Concludes that such a system is far in the future.

McDougall, Walter A.
Sputnik, the space race, and the Cold War. Bulletin of the atomic scientists, v. 41, May 1985: 20-25.

"When the United States decided to compete in space, prestige became a major factor in national security and science and technology came under the purview of the federal government."

McNamara, Robert S.
Reducing the risk of nuclear war: is Star Wars the answer? Millennium, v. 15, summer 1986: 133-141.

"Each side must recognise that neither will permit the other to achieve a meaningful superiority--attempts to gains such an advantage are dangerous as well as futile. The forces pushing both sides in the direction of first strike postures, at least from the standpoint of the adversary, must be reversed", argues the author.

Meinel, Carolyn.
Near-earth asteroids: potential bonanza for ambitious military space projects. Defense science 2003+, v. 4, Feb. 1985: 40-47.

"Because of their potential impact on strategic defense, asteroid resources may be more than just a way to cut the costs of military space operations."

Melby, Svein.
Anti satellite weapons, the strategic balance, and arms control. Oslo [Norsk Utenrikspolitisk Institutt, 1982] 152 p. (NUPI rapport; nr. 69)

Menon, P. K.
Demilitarization of outer space. International journal on world peace, v. 4, Apr.-June 1987: 127-150.

"The prevention of an arms race in outer space is important because it is an area which has been free from confict and military confrontation. The United States and the Soviet Union with their space capabilities have the primary responsibility in the prevention of an arms race in outer space."

The United Nations' efforts to outlaw the arms race in outer space: a brief history with key documents. Lewiston, N.Y., E. Mellen Press, 1988. 209 p. (Studies in world peace; v. 1)

Military satellite communications. International defense review, v. 18, no. 5, 1985: 701, 703-704, 709-711, 715-717, 721-723.

Military space doctrine. Washington, Department of the Air Force, 1982. 15 p. (Air Force manual AFM 1-6)

Contents.--National space policy, executive guidance, and legal constraints.--Military interests in space.--Air Force functions and missions in space.--Organizing, training, equipping, and sustaining space forces.--Selected bibliography for military space doctrine.

"This manual covers those elements of Air Force basic doctrine that pertain to space."

The Military uses of space. Survival, v. 25, Sept.-Oct. 1983: 194-215.

Militarization of space. Edited by Stephen Kirby and Gordon Robson. Boulder, Colo., Lynne Rienner, 1987. 253 p.

Contents.--The technological bases.--The superpowers.--Implications.

Mische, Patricia M.
Star wars and the state of our souls: deciding the future of planet Earth. Revised and enlarged. Minneapolis, Minn., Winston Press, c1985. 136 p.

Myers, David S.
Soviet proposals on the militarization of space. Space policy, v. 2, Aug. 1986: 240-252.

Examines three proposals submitted to the U.N. by the USSR, aimed at avoiding the militarization of outer space. Concludes that "several questions regarding the military aspects of space activity are left unresolved by the Soviet proposals."

National security and the U.S. space program after the Challenger tragedy. International security, v. 11, spring 1987: 141-186.

"Seven space policy experts address the questions raised by the Challenger tragedy."

Contents.--A "born again" space program, by Albert D. Wheelon.--The myths of militarization of space, by Edward C. Aldridge, Jr.--The U.S. space program: an international viewpoint, by Richard R. Colino.--National security space policy, by Richard L. Garwin.--The future of NASA and the U.S. Enterprise in space, by Hans Mark.--"Born anew" versus "born again," by Bruce Murray.--Space station: the next logical step to national distress, by James A. Van Allen.

The New military race in space. Business week, no. 2588, June 4, 1979: 139, 142, 145, 149.

The Next giant leap in space: an agenda for international cooperation; final report. New York, United Nations Association of the United States of America, c1986. 70 p.

"This report represents the consensus of a broad array of Americans on how best to work with other countries to encourage the peaceful explorations and development of" outer space.

Nitze, Paul H.
Negotiations on nuclear and space arms. Washington, U.S. Dept. of State, Bureau of Public Affairs, 1986. 4 p. (Current policy no. 807)

In this speech, Special Advisor to the President and Secretary of State on Arms Control Matters, discusses issues presented by both sides at the Nuclear and Space Arms Talks (NST).

Oberg, James E.
A dozen anti-ASAT fallacies. Air Force magazine, v. 68, July 1985: 78-81.

Outer space--a new dimension of the arms race. Edited by Bhupendra Jasani. London, Taylor & Francis, Cambridge, MA, Distributed by Oelgeschlager, Gunn & Hain, 1982. 423 p.

Outer space warfare. Pugwash newsletter, v. 21, Apr. 1984: 153-164.

Partial contents.--Weaponization of space, by E. Velikhov.--'Star wars', by J. Ruina. Papers presented at a Plenary session of the 33rd Pugwash Conference, Venice, 26-31 Aug. 1983.

Parnas, David L.
Star Wars and the scientific community. Alternatives, v. 13, Apr. 1986: 27-31.

"The Star Wars project raises two scientific and professional concerns that are worthy of broader attention."

Petrie, W.
Military activity in space--is there a choice? Canadian defence quarterly, v. 15, winter 1985-86: 31-36.

Examines space systems "necessary for such functions as gathering intelligence, the command and control of land and sea-based weapons, and in general for providing support to the strategic weapons systems."

Pike, John E.
Star Wars or star peace. F.A.S. [Federation of American Scientists] public interest report, v. 40, Nov. 1987: 5-8.

Argues that the U.S. should direct the resources of the aerospace industry toward cooperation with the Soviet Union. Suggests the U.S. could implement all of the recommendations of the Ride Report in its space program by reducing the aerospace industry's support for the arms race and Star Wars, and concentrating on reduction of superpower tensions.

Star Wars: the impossible dream. New scientist, v. 119, Sept. 1, 1988: 47-48, 50-52.

Relates how the technical feasibility of the Strategic Defense Initiative has been called into question. Proponents of the system recognize that SDI will not provide complete protection against a nuclear attack. Much of the technology needed to make SDI a reality has not been developed.

Pilat, Joseph.

Star peace: Soviet space arms control strategy and objectives. Washington quarterly, v. 10, winter 1987: 137-152.

Analyzes "a series of likely Soviet military-strategic and political objectives in the defense and space arms negotiations and, considers Soviet military objectives and prospects for an arms control agreement."

Piotrowski, John L.

The military imperatives of space. Defense issues, v. 2, no. 23, 1987: 1-5.

In this May 21, 1987 speech at the Air Force Space Association Symposium, Commander in Chief of the U.S. Space Command discusses goals of the military space program. "The overarching military space imperative is to accept the challenge to better use space to deter conflict and should deterrence fail--to fight effectively."

The U.S. antisatellite requirement: myths and facts. Armed Forces journal international, v. 125, Sept. 1987: 64-65, 68.

Pournelle, Jerry.

The decisive frontier: space. Omni, v. 4, Nov. 1981: 30, 138-139.

"Before the end of this century--probably in this decade--space weapons will end the balance of terror that has made nuclear war all but unthinkable for the last 36 years. They will make possible a global conflict whose undamaged victor could dictate terms to a disarmed and helpless loser."

The President's choice: Star Wars or arms control. Foreign affairs, v. 63, winter 1984-1985: 264-278.

"Sharing the gravest reservations about this undertaking [Strategic Defense Initiative], and believing that unless it is radically constrained during the next four years it will bring vast new costs and dangers to our country and to mankind, we [McGeorge Bundy, George Kennan, Robert McNamara and Gerard Smith] think it urgent to offer an assessment of the nature and hazards of this initiative, to call for the closest vigilance by Congress and the public, even to invite the victorious President to reconsider."

Preventing an arms race in outer space: a symposium held at United Nations headquarters, 26 January 1984. Disarmament, v. 7, summer 1984: 55-82.

Presents "an abridged transcript of a symposium sponsored by the Non-Governmental Organizations Committee on Disarmament at United Nations Headquarters on 26 January 1984."

Putting America's defense into orbit: the most radical strategic policy change since World War II. Business week, no. 2795, June 20, 1983: 52-53, 56, 60.

Reports on the national security implications of space.

Rawles, James W.

Military satellites: the next generation. Defense electronics, v. 20, May 1988: 46, 48, 52, 54, 56, 58, 60, 62-63.

"While only a small number of new military satellite systems will be entering service in the 1990s, analysts predict that they will be vigorously funded."

Rawles, Richard.

The dark side of the force. Sierra, v. 72, Sept.-Oct. 1987: 59-62.

"In 1983 President Reagan called upon the scientific community to develop a defensive system that would render nuclear weapons 'impotent & obsolete.' But close examination by concerned physicists has revealed a very different purpose behind Star Wars--one more in keeping with its cinematic namesake."

The Reality behind 'star warfare'. International currency review, v. 15, July 1983: 36-42.

"Expenditure on space warfare is going to exert additional open-ended pressures on the dollar financial system through opening a further dimension of headlong deficit-spending, which the collective ingenuity of the Federal bureaucy will be unable to offset or disguise."

Recommended changes in U.S. military space policies and programs; a paper by the Working Group on Technology, submitted to the Commission on Integrated Long-Term Strategy. Washington, The Commission, for sale by the Supt. of Docs., G.P.O., 1988. 10 p.

Details programs and policies regarding U.S. military space programs. Offers specific recommendations in each area.

Rekenthaler, Douglas A.

Satellite surveillance: new policy issues? Journal of defense & diplomacy, v. 3, Sept. 1985: 15-19.

"Today's intensity in exploitation, exploration and warfare in space has profound implications. Leaders of this move into space--the United States, the USSR, France, West Germany and Japan--must now address space policy issues that have long-term, worldwide effects, touching defense, balance of payments and human welfare in myriad ways."

Report to Congress on the capabilities of the SDI National Test Bed. Prepared by the Strategic Defense Initiative Organization. Washington, U.S. Dept. of Defense, Strategic Defense Initiative Organization, 1988. 12, 1 p.

"This report has been prepared for the Committees on Appropriations of the United States Senate and House of Representatives pursuant to the requirements of Section 125 of the fiscal year 1988 Military Construction Appropriations Act, HJ Resolution 395, P.L. 100-202 . . . The criteria which the President has set forth for a Strategic Defense System (SDS) are military effectiveness, survivability, and cost-effectiveness. If deployed, SDS will be more complex than any other system the world has seen. Its military effectiveness and survivability can never be completely and fully tested as a whole, short of the actual conditions of full scale conflict. Thus, the National Test Bed Program was created. The NTB will be the pivotal research and development tool providing the capability to develop and evaluate SDS architectures, human interface elements, and component technologies."

"Resolved: we should go full speed ahead on Star Wars." Southern Educational Communications Association, 1985. 42 p. (Firing line, no. 643-644)

"This is a transcript of the Firing Line program taped in Columbia, South Carolina, on April 25, 1985, and telecast later by PBS."

Examines issues surrounding the Star Wars proposal.

Richardson, Robert C.

Security, space, and cost: a new, affordable, defense proposal. Journal of social, political and economic studies, v. 14, spring 1989: 3-24.

"The new U.S. Congress and Administration inherited three major problems that are interrelated: How to perpetuate a credible U.S. and NATO security posture; . . . How to best assure access to, and exploit space for the benefit of the US and the Free World, and how to cope with the deficit."

Richelson, Jeffrey T.

America's secret eyes in space: the U.S. keyhole spy satellite program. New York, Harper & Row, 1990. 375 p.

Rip, Michael R.

Military photo-reconnaissance from space: isn't it time to spy for peace? International affairs bulletin, v. 11, no. 1, 1987: 38-45.

"Reconnaissance satellites do not necessarily have to represent instruments of sophisticated modern warfare, but could just as easily be a vital ingredient in the promotion of bilateral nuclear arms control treaties and ultimately, global security."

Ritchie, David.

Sky spies. Technology illustrated, v. 2, Oct.-Nov. 1982: 81-82, 84, 86.

Spacewar. New York, New American Library [1983] c1982. 224 p.

Robinson, George S.

Militarization and the Outer Space Treaty--time for a restatement of "space law". Astronautics & aeronautics, v. 16, Feb. 1978: 26-29.

Space law, space war and space exploitation. Journal of social and political studies, v. 5, fall 1980: 163-178.

Assesses how current space law will effect long-term private risk capital investment in space exploitation.

Roe, Linas A. Wise, Douglas H.

Space power is land power: the Army's role in space. Military review, v. 66, Jan. 1986: 4-17.

"Over the past four decades, the Army has changed from a pioneer service to a service with less than clear goals, a fragmented, organizational approach and no formal space policy."

Roling, Bert V. A. Sukovic, Olga.

The law of war and dubious weapons. Stockholm, Stockholm International Peace Research Institute [1976] 78 p.

Contents.--The principles of the law of war.--Application of the principles of the law of war to new weapons.

Russell, Malcolm.

Military activities in outer space: Soviet legal views. Harvard international law journal, v. 25, winter 1984: 153-193.

"This Comment sets forth a foundation for examination of Soviet space law by presenting the current military situation in space and the inadequancy of existing international regulation of space military activities. Next, it explores Soviet views on international law relating to space in general, and military activities in particular."

Sagan, Carl.

Star Wars: the leaky shield. Parade magazine, Washington post, Dec. 8, 1985: 11, 13, 16-17.

Discusses the Soviet-U.S. arms race since world War II and evaluates the possible effect of the Star Wars program. States that putting weapons in space would be dangerous and destabilizing. Concludes that enough Soviet warheads would get through to destroy the U.S. anyway.

Sagan, Carl. Garwin, Richard L.

Ban space weapons. Bulletin of the Atomic Scientists, v. 39, Nov. 1983: 2-3.

"Two eminent scientists have initiated a petition urging the United States and the Soviet Union to ban all weapons from space. The petition is dated February 24, 1983, one month earlier than President Reagan's speech advocating a space-based defense against strategic missiles." Presents a partial list of signatures.

Salkeld, Robert.

War and space. Englewood Cliffs, N.J., Prentice-Hall, 1970. 195 p.

Sanders, Kevin.

Etiquette for the age of transparency: public access to public monitoring from space. Whole Earth review, no. 50, spring 1986: 56-64.

The new European satellite called SPOT is the world's most powerful civilian earth observation system, producing pictures three times more detailed than those of Landsat. The availability of high resolution photos which can detect anything on the Earth's surface which is at least 33 feet wide, has important implications for defense and foreign policy.

SDI: more spin-offs than Apollo? Defense electronics, v. 20, May 1988: 39-41, 43-45.

"Some market analysts predict that the SDI program could pay for itself by generating technological spin-offs that will foster economic growth."

SDI: the "Star Wars" project. New York, George C. Marshall Institute, 1985. 36 p.

Contents.--A new strategic vision.--Protection for the 1990s.--Ways to counter the defense.--Frequently asked questions about "Star Wars."

The Search for security in space: a congressional seminar, March 19, 1986. Washington, American Association for the Advancement of Science, 1987. 100 p. in various pagings.

Contents.--Overview: the military use of outer space.--Treaty restrictions on the military use of outer space.--Evaluating space weapon technology.--Impact of space weapons on U.S. national security.--Resources.

Seeking stability in space: anti-satellite weapons and the evolving space regime, editors, Joseph S. Nye, Jr. and James A. Schear. [Queenstown, Md.] Aspen Strategy Group; Lanham, Md., University Press of America, c1987. 167 p.

Sheehan, Michael.
Confidence-building in space. World today, v. 42, Mar. 1986: 42-45.

Describes past American-Soviet space cooperation and urges that it should be strengthened and made multi-lateral. States that "there are many reasons why the development of American-Soviet cooperation in space should prove of major benefit to superpower and international relations generally. They can be seen as confidence-building measures (CBMs) in themselves."

Siegel, Lenny.
Space wars: the Air Force readies a grand finale untouched by human hands. Progressive, v. 46, June 1982: 27-29.

"Most of the world is still a long way from understanding how busily the Earth and its environs are being wired right now for nuclear war."

Simpson, John. Acton, Philip. Crowe, Simon.
The Israeli satellite launch. Space policy, v. 5, May 1989: 117-128.

Speculates on the political and arms control consequences of Israel's satellite launch.

Smith, Milton L.
Legal implications of a space-based ballistic missile defense. California Western international law journal, v. 15, winter 1985: 52-75.

The article examines "the legal aspects of the proposed space-based BMD systems. Only the American proposals will be examined since little is known of the Soviet efforts in this area."

Smith, Willis.
Military buildup in space--a threat to national security. Thurgood Marshall law review, v. 10, spring 1985: 158-183.

This note proposes that the United States and the Soviet Union begin to articulate policies to prevent military build-up in space.

Soviet military power; prospects for change, 1989. 8th ed. Washington, U.S. Dept. of Defense, for sale by the Supt. of Docs., G.P.O., 1987. 159 p.

The Soviet space challenge. [Washington?] Dept. of Defense, 1987. 20 p.

The Space factor. National review, v. 40, Dec. 9, 1988: 18.

As many in the United States seek to 'refine' SDI away from space-based systems--perhaps in an effort to make missile defense more 'acceptable' to the Soviets--they would do well to remember that space is more important to our conventional deterrent than are our dwindling nuclear forces."

Space Symposium (1984: Washington, D.C.)
America plans for space: a reader based on the National Defense University Space Symposium. Washington, National Defense University Press, for sale by G.P.O., 1986. 196 p.

Space weapons. Bulletin of the atomic scientists, v. 40, May 1984: 1S-15S.

Contents.--History and current debate, by R. Garwin and J. Pike.--Effect on strategic stability, by Y. Velikov.

Space-based defense systems: market study and forecast. Greenwich, Conn., (100 Northfield St., Greenwich, 06830), Defense Marketing Services, c1984. 1 v. (in various pagings)

Space-based missile defense: a report by the Union of Concerned Scientists. Cambridge, Mass., The Union, 1984. 106 p.

Space weapons and international security. Edited by Bhupendra Jasani. Oxford [Oxfordshire]; New York, Oxford University Press, 1987. 366 p.

Based on the proceedings of a conference held in Stockholm in July, 1985.

Space weapons--the arms control dilemma. Edited by Bhupendra Jasani. Stockholm International Peace Research Institute; London, Philadelphia, Taylor & Francis, 1984. 255 p.

Space weapons policy. Congressional digest, v. 63, Mar. 1984: 67-96.

Special issue on anti-satellite weapons. Journal of the Federation of American Scientists, v. 36, Nov. 1983: whole issue.

Spring, Baker.

Zenith Star experiment to test laser weapon in space. Washington, Heritage Foundation, 1989. 2 p. (Backgrounder no. 107)

Updates an earlier Heritage study on the SDI timetable (Jan. 1987).

Star Wars. In Beyond Reagan: the politics of upheaval. Edited by Paul Duke. New York, Warner Books, 1986. p. 194-234.

The article is followed by a roundtable discussion, p. 220-234.

The "Star Wars" controversy: pro and con. Congressional digest, v. 64, Mar. 1985: whole issue (69-96 p.)

Contents.--Presidential policy statement.--Program administration.--Operational characteristics.--The treaty factor.--Recent action in the Congress.

The Star Wars debate. Edited by Steven Anzovin. New York, H. W. Wilson, 1986. 223 p. (Reference shelf, v. 58, no. 1)

Contents.--The challenge.--Can it be done?--Should it be done?--World opinion.

Star Wars: pro and con. Discover, v. 6, Sept. 1985: 66-74.

Contents.--Pro, by E. Teller.--Con, by C. Sagan.

Stares, Paul B.

ASAT weapons: why restraint makes sense. Brookings review, v. 5, fall 1987: 3-9.

"The fate of the U.S. antisatellite (ASAT) program hangs in the balance. The reason: Congress is poised to renew a moratorium that for the fourth straight year would impose strict limits on the testing of an air-launched missile designed to attack Soviet satellites . . . . The continuation of the moratorium could convince the Air Force to restructure the program entirely or even cancel it outright."

The militarization of space: U.S. policy, 1945-1984. Ithaca, N.Y., Cornell University Press, 1985. 334 p. (Cornell studies in security affairs)

Space and national security. Washington, Brookings Institution, c1987. 219 p.

"Assesses the long-term costs and benefits of developing ASAT weapons and the feasibility alternative policies."

Space weapons and U.S. strategy: origins and development. London, Croom Helm, c1985. 334 p.

Stashevsky, Sergei. Stakh, Gennadi.

Outer space must be free from weapons. Social sciences, v. 14, no. 2, 1983: 189-198.

"The rapid development of space technology has made the task of preventing the spread of the arms race to outer space an urgent and primary one."

Stein, Jonathan B.
From H-bomb to star wars: the politics of strategic decision making. Lexington, Mass., Lexington Books, 1984. 118 p.

Steinberg, Gerald.
The ultimate battleground: weapons in space. Technology review, v. 84, Oct. 1981: 57-63.

"Increasingly widespread notions of orbiting death rays and celestial Waterloos are mainly the stuff of speculation, for wars in space are more picturesque than practical."

Stine, G. Harry.
Confrontation in space. Englewood Cliffs, N.J., Prentice-Hall, 1981. 209 p.

Stockholm International Peace Research Institute.
Outer space: battlefield of the future? London, Taylor and Francis, 1978. 202 p.

The Strategic Defense Initiative: five years of progress. Arms control update, no. 5, Apr. 1988: 4-5.

Presents a chronology concerning the Strategic Defense Initiative from Mar. 1983 to Mar. 1988.

Strategic defenses: alternative missions and their costs. Washington, Congressional Budget Office, for sale by the Supt. of Docs., G.P.O., 1989. 81 p.

"This special study seeks to inform the Congressional debate on the SDI by analyzing four alternative missions, which vary widely in their costs and in the defense capability that would result. In keeping with the mandate of the Congressional Budget Office (CBO) to provide objective analysis, the report does not recommend any particular course of action."

Strategic defenses and Soviet-American relations. Edited by Samuel F. Wells, Jr. and Robert S. Litwak. Cambridge, Mass., Ballinger Pub. Co., 1987. 216 p.

Strategic defenses: two reports, by Office of Technology Assessment. Princeton, N.J., Princeton University Press, 1986. 146 p.

Contents.--Ballistic missile defense technology.--Antisatellite weapons, countermeasures, and arms control.

Sundaram, Gowri S.
U.S. military space programs: emphasis on survivability. International defense review, v. 17, no. 8, 1984: 1019-1021, 1023-1024, 1029-1030.

Sweet, William.
Science wars over Star Wars. Washington, Congressional Quarterly, 1986. p. 687-708. (Editorial research reports, 1986, v. 2, no. 11)

Contents.--Scientists divided over Star Wars.--Nuclear age heralds weaponry debate.--Technology choices behind Star Wars.

Symposium on the Strategic Defense Initiative. Journal of legislation, v. 15, no. 2, 1989: whole issue (77-276 p.)

Tarver, Robert.
Why America's military services balk at the Strategic Defense Initiative. Washington, Heritage Foundation, 1989. 15 p. (Backgrounder no. 721)

"The American military services "are not very comfortable" with the Strategic Defense Initiative because it threatens 'parochial interests among the military.'"

Taylor, L. B.
Space: battleground of the future? 2nd ed. New York, F. Watts, 1988. 144 p. (An Impact book)

Teller, Edward.
Scientists and national defense: an open letter to Hans Bethe. Policy review, no. 39, winter 1987: 18-23.

Concludes that "if scientists are not interested in SDI, this certainly will have consequences both for science and also for our political future."

Tirman, John.
Star Wars technology threatens satellites. Bulletin of the atomic scientists, v. 42, May 1986: 28-32.

"Star wars would make any space-based system vulnerable, since the resulting weapons could more easily be turned against satellites than against missiles." The increased threat to satellites so crucial to the maintenance of stability, arms control, and readiness means that, even if it fails, the SDI will succeed in undermining U.S. security.

Toth, Robert C.
War in space. Science 80, v. 1, Sept. 1980: 74-80.

"Military satellites and exotic weaponry threaten to turn space into the next battleground."

U.S. Congress. House. Committee on Armed Services. Defense Policy Panel.
SDI program. Hearings before the Defense Policy Panel and Research and Development Subcommittee of the Committee on Armed Services, House of Representatives, 100th Congress, 1st session. Mar. 26, July 8, and Sept. 15, 1987. Washington, G.P.O., 1988. 304 p.

At head of title: H.A.S.C. no. 100-31."

U.S. Congress. House. Committee on Armed Services. Strategic Defense Initiative Panel.
Special panel on the Strategic Defense Initiative. Hearings, 100th Congress, 2nd session. Apr. 20-Oct. 4, 1988. Washington, G.P.O., 1989. 487 p.

At head of title: H.A.S.C. no. 100-90.

This hearing "explores ground-based architectures compliant with the ABM Treaty that might be deployed before the turn of the century."

U.S. Congress. House. Committee on Foreign Affairs.
Fiscal year 1990 arms control impact statements. Washington, G.P.O., 1989. 189 p.

At head of title: 101st Congress, 1st session, Joint committee print.

Contents.--U.S. arms control policy.--Arms control impact analyses.--Strategic offensive forces.--Strategic defense initiative.--Chemical weapons.--Treaty annex.

U.S. Congress. House. Committee on Foreign Affairs. Subcommittee on International Security and Scientific Affairs.
Arms control in outer space. Hearings held Nov. 10, 1983-July 26, 1984. Hearings, 98th Congress. Washington, G.P.O., 1984. 480 p.

U.S. Congress. House. Committee on Foreign Relations. Subcommittee on Arms Control, International Security and Science.
Implications of the President's Strategic Defense Initiative and antisatellite weapons policy. Hearings, 99th Congress, 1st session. Apr. 24 and May 1, 1985. Washington, G.P.O., 1985. 245 p.

U.S. Congress. House. Committee on Government Operations. Legislation and National Security Subcommittee.
Cost estimates for phase I of the Strategic Defense Initiative. Hearing, 101st Congress, 1st session. Mar. 21, 1989. Washington, G.P.O., 1989. 99 p.

"Examines how the Strategic Defense Initiative Organization developed its cost estimate for phase I and what these cost estimates mean in terms of actual appropriations."

Management of the Strategic Defense Initiative. Hearing, 100th Congress, 2nd session. Mar. 29, 1988. Washington, G.P.O., 1988. 94 p.

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production.
Space nuclear power generation, conversion and storage for the nineties and beyond; report. Washington, G.P.O., 1986. 16 p.

At head of title: Committee print.

"Serial H"

U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Strategic Forces and Nuclear Deterrence.
Air Force space launch policy and plans. Hearing, 100th Congress, 1st session. Oct. 6, 1987. Washington, G.P.O., 1988. 50 p. (Hearing, Senate, 100th Congress, 1st session, S. Hrg. 100-505)

U.S. Congress. Senate. Committee on Foreign Relations.
Controlling space weapons. Hearings, 98th Congress, 1st session on S. Res. 43 and S. J. Res. 28. Apr. 14 and May 18, 1983. Washington, G.P.O., 1983. 173 p. (Hearing, Senate, 98th Congress, 1st session, S. Hrg. 98-141)

Outer space arms control negotiations; report to accompany S.J. Res. 129. Washington, G.P.O., 1983. 16 p. (Report, Senate, 98th Congress, 1st session, no. 98-342)

Strategic defense and anti-satellite weapons. Hearing, 98th Congress. Apr. 25, 1984. Washington, G.P.O., 1984. 361 p. (Hearing, Senate, 98th Congress, 2nd session, S. Hrg. 98-750)

U.S. Congress. Senate. Committee on Foreign Relations. Subcommittee on Arms Control, Oceans, International Operations and Environment.
Arms control and the militarization of space. Hearing, 97th Congress, 2nd session, on S. Res. 129. Sept. 20, 1982. Washington, G.P.O., 1982. 69 p.

S. Res. 129 "Expressing the sense of the Senate with respect to resumption of negotiations between the United States and the Union of Soviet Socialist Republics on the limitation of Antisatellites (ASAT) weapons systems."

U.S. Congress. Senate. Committee on Governmental Affairs. Subcommittee on Oversight of Government Management.
Need for and operation of a Strategic Defense Initiative Institute. Joint hearing before the Subcommittee on Oversight of Government Management of the Committee on Governmental Affairs and the Subcommittee on Governmental Affairs and the Subcommittee on Strategic Forces and Nuclear Deterrence of the Committee on Armed Services, United States Senate, 100th Congress, 1st session. May 6, 1987. Washington, G.P.O., 1987. 229 p. (Hearing, Senate, 100th Congress, 1st session, S. Hrg. 100-137)

"A proposal by the Defense Department to establish a new Federally-Funded Research and Development Center, or FFRDC, devoted solely to the Strategic Defense Initiative Institute, or SDII."

U.S. Dept. of Defense.
The Soviet space challenge. Washington, The Department 1987. 20 p.

Contends that the Soviet Union "has worked steadily to acquire a military capability in space. Because the Western democracies, particularly the United States, have directed a large part of their space resources and technology toward other goals, and sometimes have lacked clear goals, we have allowed the Soviet Union to come dangerously close to achieving its military objectives in space. The Soviets have methodically designed their space systems to fight a war in space."

Strategic Defense Initiative: 1989 report to the Congress. Washington, The Dept., 1989. ca. 250 p. in various pagings

"1989 Report to Congress on the Strategic Defense Initiative, as required by Section 231 of the FY 1988/1989 Department of Defense Authorization Act. This report serves as a summary of the SDI legacy of President Reagan, who launched the initiative with his historic speech of March 23, 1983. In addition, General James Abrahamson, the first Director of the Strategic Defense Initiative Organization, will retire at the end of January. This report also serves as a summary of where his able leadership has brought the program."

Strategic Defense Initiative: progress and promise. Washington, U.S. Dept. of Defense, 1989. 31 p.

"This pamphlet reports to the nation on the reasons behind, and progress toward the goals of the Strategic Defense Initiative."

Partial contents.--How would defenses work?--How do we achieve effective defenses?--What are some of SDI's achievements in defensive technologies?--Does strategic defense cost too much money?--Are there other uses for strategic defense technology?--Should we continue to explore strategic defenses?

U.S. General Accounting Office.

Military space operations: shuttle and satellite computer systems do not meet performance objectives; report to the chairman, Subcommittee on Defense, Committee on Appropriations, House of Representatives. Aug. 5, 1988. Washington, G.A.O., 1988. 44 p.

"GAO/IMTEC-88-7, B-205335"

Military space operations: use of mobile ground stations in satellite control; report to the Honorable John P. Murtha, chairman, Subcommittee on Defense, Committee on Appropriations, House of Respresentatives. July 3, 1989. Washington, G.A.O., 1989 15 p.

"GAO/IMTEC-89-53, B-224148"

"A requirement for mobile ground stations to provide command and control instructions to maintain the position of a satellite in orbit as well as to provide the capability to process information coming from satellites."

Space defense: management and technical problems delay operations center acquisition; report to the Chairman, Subcommittee on Defense, Committee on Appropriations, House of Representatives. Apr. 20, 1989. Washington, G.A.O., 1989 60 p.

"GAO/IMTEC-89-18, B-203028"

Evaluates "how well the Air Force has managed the Space Defense Operations Center modernization effort. The replacement system will be an integral part of the North American Aerospace Defense Command's ability to provide space surveillance and satellite attack warning information."

Strategic Defense Initiative Program: information on reprogramming and Department of Energy efforts; fact sheet for the Chairman, Legislation and National Security Subcommittee, Committee on Government Operations, House of Representatives. May 27, 1988. Washington, G.A.O., 1988. 11 p.

"GAO/NSIAD-88-162FS, B-223094"

"The Stragetic Defense Initiative Organization's (SDIO) reprogramming of appropriated funds and the Department of Energy's (DOE) role in the Strategic Defense Initiative (SDI) program."

Strategic Defense Initiative Program: Zenith star space-based chemical laser experiment. Apr. 14, 1989. Washington, G.A.O., 1989. 37 p.

"GAO/NSIAD-89-118, B-223094"

A review of "selected aspects of chemical laser research managed by the Strategic Defense Initiative Organization."

Ulsamer, Edgar.

Safeguarding space. Air Force magazine, v. 60, Apr. 1977: 34-38.

United Nations. Dept. for Disarmament Affairs.

The United Nations General Assembly and disarmament 1986. New York, United Nations, 1987. 229 p.

VanCleave, William R.
The U.S.-Soviet military balance and arms control. Global affairs, v. 4, spring 1989: 1-18.

"Despite widely held impressions to the contrary, the U.S.-Soviet military balance continued to worsen between 1981 and 1989. For several reasons, including arms control and U.S. failure to bring SDI to fruition, the prospects for improving and stabilizing that balance seem less favorable today than eight years ago, and standards for evaluating U.S. military capabilities are quietly being lowered."

Voute, Cesar.
A European military space community: reality or dream? Space policy, v. 2, Aug. 1986: 206-222.

States that European space policy is at a crossroads and that one of the major policy issues is whether Europe should expand its space program in a military framework. Concludes that Europeans should develop non-nuclear and non-aggressive defense based on emerging technologies and new military doctrines and that "for these purposes, the establishment of a military space community would not provide the proper structure."

Waldman, Harry.
The dictionary of SDI. Wilmington, Del., Scholarly Resources, c1988. 182 p.

"The aim of this dictionary is to clarify and simplify SDI's complex terrain, lay out the technology involved, and identify those areas under debate. The material is presented in a straightforward A-to-Z fashion, with accompanying illustrations in many cases."

Weaponry in space: the dilemma of security. [Washington] Foreign Broadcast Information Service, 1987. 122 p.

"JPRS-TAC-87-001-L, 15 January 1987"

At head of title: Worldwide report.

Contents.--Hypothetical space-based components of a ballistic-missile defense.--Space-based battle stations.--Some technical issues of terminal defense.--Potential uses of space-based weapons against air and ground targets.--Support components.--Countermeasures.--Strategic and political aspects.--Legal aspects.--Spin-offs of SDI research efforts.

Weapons in space. Computers and people, v. 34, Mar.-Apr. 1985: 15-18, 27.

"It is a dangerous myth that space weapons could be used only for defensive purposes."

Weapons in space. Daedalus, v. 14, spring 1985: whole issue (9-192 p.); summer 1985: whole issue (193-397 p.)

Partial contents.--Vol. 1. Concepts and technologies.--Nuclear deterrence and the military uses of space, by H. York.--The Strategic Defence Initiative, by G. Yonas.--Assessing the President's vision: the Fletcher, Miller, and Hoffman Panels, by D. Hafner.--Anti-satellite weapons: weighing the risks, by K. Gottfried and R. Lebow.--Vol. 2. Implications for security.--BMD and strategic instability, by G. Rathjens and J. Ruina.--The Strategic Defense Initiative and the Soviet Union, by D. Holloway.--The SDI and U.S. security, by J. Boutwell and F. Long.

Weapons in space. Edited by Franklin A. Long, Donald Hafner, and Jeffrey Boutwell. 1st ed. New York, Norton, c1986.

This work is expected to be available later in 1990.

Weapons in space: the controversy over 'Star Wars.' New York times, Mar. 3, 1985: 1, 10; Mar. 4: A1, A8; Mar. 5: A1, A16; Mar. 6: A1, B8; Mar. 7: A1, A24; Mar. 8: A1, A14.

Contents.--Vision of space defense posing new challenges, by L. Gelb.--Reagan's 'Star Wars' bid: many ideas converging, by W. Broad.--'Star Wars' technology: it's more than a fantasy, by W. Biddle.--What Moscow might do in replying to 'Star Wars,' by C. Mohr.--Dark side of 'Star Wars': system could also attack, by P. Boffey.--'Star Wars' and mankind: consequences for the future, by P. Boffey.

Weinberg, Alvin M. Barkenbus, Jack N.
Stabilizing star wars. Foreign policy, no. 54, spring 1984: 164-170.

Weinberger, Caspar W.

Space: vital to U.S. national security. Arms control update, no. 2, Nov. 1987: 1.

Former Secretary of Defense contends that "it is not the militarization of space we must fear--that took place thirty years ago--but the dominance of space by forces hostile to liberty."

Whelan, C. Richard.

Guide to military space programs. Arlington, Va., Pasha Pub., 1984. 156 p.

Contents.--Service roles and missions in space.--Military satellite communications programs.--Reconnaissance and surveillance.--Navigation satellites.--Space weapons.--Operational support programs.--Related development and test programs.

Wood, Lowell L.

'Brilliant Pebbles' missile defense concept advocated by Livermore scientist. Aviation week & space technology, v. 128, June 13, 1988: 151-152, 155.

Senior staff physician at Lawrence Livermore National Laboratory reviews the "Brilliant Pebbles" concept. "Constituted only of technologies that are manifestly non-sensitive--non-nuclear, commerical and in many cases consumer technologies--this brilliant pebble-based strategic defense system could be fully shared with the Soviet Union with minimal complications for national security."

Worden, Simon P. Jackson, Bruce P.

Space, power, and strategy. National interest, no. 13, fall 1988: 43-52.

"In the years to come, the military force that matters will be based in space. This is a development that those responsible for the national security cannot ignore." Discusses space in offense and defense, space in Soviet strategy and strategic choke points in space.

Yarymovych, M. I.

The case for weapons in space. National security record, no. 116, Sept. 1988: 5.

Presents excerpts from a speech by Yarymovych, Vice President of Rockwell International, "delivered at the AFCEA Space Symposium at Colorado Springs on August 11, 1988."

Zedalis, Rex J.

On the lawfulness of forceful remedies for violations of arms control agreements: "Star Wars" and other glimpses at the future. New York University journal of international law and politics, v. 18, fall 1985: 73-167.

Since March 23, 1983, a national and international debate has swirled around the implications of the Strategic Defense Initiative (SDI). Some have argued that placing defensive weapons in space will violate arms control agreements . . . . Professor Zedalis looks one step further and asks whether, given such a violation, the Soviet Union might be permitted under international law to remove forcefully the components of the SDI system." The author attempts to determine the validity of forceful measures and anticipatory self-defense doctrines in light of the U.N. Charter.

Zimmerman, Peter D.

Pork bellies and SDI. Foreign policy, no. 63, summer 1986: 76-87.

"The crucial point is that in strategic defense, as in pork bellies speculation, leverage entails risks. In the latter, one can lose borrowed funds that remain outstanding and be saddled with an upaid contract. But the failure of a highly leveraged missile defense system would mean nuclear disaster."

What Should be the United States Government Policy Toward the Region Beyond Earth's Atmosphere?

A Guide to Information Sources on the 1990-1991 High School Debate Topic

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Library Services Division

March 1990

CONTENTS

INTRODUCTION 697

RESEARCH SOURCES 698

PART I: GENERAL REFERENCE SOURCES 699
- BOOKS 699
- ENCYCLOPEDIAS AND DIRECTORIES 700
- JOURNAL ARTICLES 700
- NEWSPAPER ARTICLES 701
- ONLINE DATABASES 702
- CD-ROM DATABASES 703
- GOVERNMENT PUBLICATIONS 703
- LEGISLATIVE INFORMATION 704
- BILLS AND RESOLUTIONS 705
- STATISTICAL SOURCES 705

PART II: REFERENCE SOURCES ON SPACE POLICY 707
- REFERENCE BOOKS 707
- INDEXES, ABSTRACTS, AND CONTENTS SERVICES 712
- SELECTED PERIODICALS 714
- FEDERAL GOVERNMENT AGENCIES 716

A GUIDE TO INFORMATION SOURCES
on the 1990-1991 High School Debate Topic

INTRODUCTION

This research guide identifies sources of information on U.S. space policy and related topics that will be discussed by high school debaters. It describes reference and research tools and suggests particular search strategies that can be used to retrieve information on these topics. The guide is divided into two parts; the first part describes basic research materials, and the second describes specialized materials relating to the issue of space policy.

In some cases, search terms are provided for each resolution of the debate topic. In other cases, only a few general terms on the topic are provided. These search terms are not exhaustive. The primary terms are included to help the debaters begin their search for supporting materials on the range of issues relating to space policy.

The individual topics are closely linked. As debaters focus on individual resolutions, and on the general issue of space policy, they will also need to scan selected relevant search terms listed under the other resolutions.

In this guide, the resolutions are referred to in the abbreviated form listed below in parentheses following each resolution.

OUTER SPACE: What should be the United States Government policy toward the region beyond Earth's atmosphere? **(General)**

Resolved: That the United States Government should significantly increase space exploration. **(Exploration)**

Resolved: That the United States Government should significantly increase commercial development of space. **(Commercialization)**

Resolved: That the United States Government should significantly increase its military use of space. **(Militarization)**

Although printed sources are emphasized in this guide, debaters should also take note of the Federal, State, and local agencies, and the non-governmental organizations listed in the section on further contacts at the end of the guide. These offices may be able to furnish additional information or publications on various policy options.

RESEARCH SOURCES

This is a list of key information resources described in this guide, and the page where each is described.

Aerospace Database 712
AeroSpace Facts and Figures 706
Air University Library Index to Military Periodicals 712
American Statistics Index 705
Applied Science & Technology Index 712
Arms Control Reporter 712
Aviation/Aerospace Online 712
Bell and Howell Newspaper Indexes 702
Books in Print 699
BRS 702
Business Periodicals Index 712
CIS Index 705
Congressional Index 705
Congressional Quarterly Weekly Report 704
Congressional Record 704
DataTimes 703
Depository Libraries 703
DIALOG 702
Digest of Public General Bills and Resolutions 705
Educational Resource Information Clearinghouse (ERIC) 703
Encyclopedia of Associations 700
Government Reports Announcements and Index 703
Index To Legal Periodicals 701
International Aerospace Abstracts 713
Library of Congress Subject Headings 699
Magazine Index 701
Major Legislation of the Congress 705
Monthly Catalog of United States Government Publications 704
NASA Pocket Statistics 706
NASA Spacelink 713
National Journal 704
National Newspaper Index 702
New York Times Index 701
NEXIS 703
NTIS (National Technical Information Service) 713
Official Washington Post Index 701
Public Affairs Information Service 701
Reader's Guide To Periodical Literature 701
Science Citation Index 713
Scientific and Technical Aerospace Reports (STAR) 713
Sears List of Subject Headings 699
Social Science Citation Index 713
Social Sciences Index 714
Statistical Abstract of the United States 705
Statistical Reference Index 706
Treaties in Force: A list of treaties and other international 704
University Microfilms Newspaper Indexes 702
VUTEXT 703
Wall Street Journal Index 702
Weekly Compilation of Presidential Documents 704
WilsonLine 703

PART I: GENERAL REFERENCE SOURCES

BOOKS

Many libraries around the country, particularly large academic and research libraries, use Library of Congress classification numbers to organize their collections, and Library of Congress subject headings in their catalogs. To learn how books on U.S. space policy are categorized in these libraries, consult the three-volume guide, *Library of Congress Subject Headings*. It is usually kept near the card catalog, or near the terminals for an automated catalog. The most relevant LC subject headings for research on space policy are listed below:

General:	Astronautics Astronautics and state Astronautics in astronomy Outer space Space law Space sciences
Exploration:	Outer space--Exploration Space colonies Space flight Space ships Space shuttles Space stations
Commercialization:	Space industrialization Launch vehicles (Astronautics)
Militarization:	Space warfare Space weapons

In many school and public libraries, books are arranged by the Dewey Decimal classification system. In these libraries, books are usually assigned subject headings from the *Sears List of Subject Headings*, also generally found near the card catalog. The most relevant terms from this resource are astronautics and civilization, space colonies, space industrialization, spaceships, outer space, space warfare, and space weapons.

If you have trouble locating books that are listed here or in other bibliographic sources, ask your librarian about *Books in Print* and about interlibrary loan. *Books in Print* will be useful in identifying the addresses of publishers for the purchase of materials, and in identifying additional and recently published books. Look particularly under the term: Science--Astronomy. Interlibrary loan may make it possible for your library to borrow materials you have identified, but that your library does not have available, from other libraries. The specialized catalog, *Scientific and Technical Books and Serials in Print*, will also be very useful for researching this topic. Search terms include outer space, space sciences, space flight, and space weapons.

ENCYCLOPEDIAS AND DIRECTORIES

Encyclopedias

Most libraries carry a selection of encyclopedias; these can be an excellent starting point in gathering basic background information on a topic. Subject headings vary from one publication to another; begin by checking the index volume(s) for basic keywords like space, space exploration, and astronautics. Encyclopedia articles often have bibliographies appended, which can be used to locate additional information on the topic. The *McGraw-Hill Encyclopedia of Science and Technology* is an example of an expecially useful resource in the area of space policy.

Encyclopedia of Associations

This annual reference source includes information on over 30,000 national and international organizations. The *Encyclopedia of Associations* consists of three volumes: the first volume, which has three parts, includes descriptive entries, as well as subject, name, and keyword indexes; the second volume contains indexes allowing searches by geographic location or executive officers' surnames; and the third volume has information on newly formed and newly found associations. This reference source can be used to locate a variety of nonprofit, nongovernmental organizations in the area of space policy and research.

A compansion volume is the *Encyclopedia of Associations--International* Organizations. This work provides information on over "9,000 international nonprofit membership organizations, including multinational and binational groups and national organizations based outside the United States, concerned with all subjects and areas of activity." Part 1 is comprised of descriptive listing and Part 2 is indexes.

Directory of Directories

This publication serves as a guide to the many catalogs, encyclopedias, checklists, and other compilations of information that exist in print. Any publication which includes addresses of individuals or organizations is eligible for inclusion in this resource. It lists a wide range of publications, including lists of cultural institutions, directories of professional organizations and societies, and membership lists of a variety of special interest groups. This resource can be used to locate more specialized directories of organizations and individuals involved in the field of space policy. Entries are grouped by subject categories, and the publication includes a title and a subject index.

JOURNAL ARTICLES

Citations to journal articles and other materials about space policy can be found in a number of printed indexes and online bibliographic databases.

The materials covered by selected printed indexes are briefly described here, along with recommended search terms for each. Printed indexes include lists of periodicals indexed and the abbreviations referring to these publications.

Online bibliographic databases are useful for locating citations to journal articles and other materials quickly through use of a computer. Online databases allow the researcher to combine search terms in ways that are impossible in a printed index or library catalog, and to simultaneously search material that would be contained in separate printed indexes covering several years. They also are updated more frequently than most printed tools. Many of the printed indexes described in this guide are also available as online databases.

Brief descriptions of some major online services providing access to bibliographic databases are provided. A reference librarian can advise you on the availability of computerized search services in your area; there is often a fee for the use of these services.

Magazine Index

Magazine Index provides citations to materials in over 400 popular magazines, focusing on coverage of current affairs, leisure time activities, arts, sports, and science and technology. References from the last five years are listed alphabetically by subject and author in one alphabetical display on the *Magazine Index* microfilm reader-terminal. The index is updated monthly, and uses Library of Congress subject headings.

Public Affairs Information Service (PAIS)

PAIS is a subject index of books, pamphlets, government publications, reports of public and private agencies, and periodical articles relating to political, economic, and social conditions, public administration, and international affairs. It is issued monthly; there are also three quarterly cumulations and an annual bound volume with an author index. Some search terms you may be able to use in *PAIS* include: Space, outer; Space research; Space technology; Space fight, Space vehicles.

Reader's Guide To Periodical Literature

The *Reader's Guide* is an author/subject index to over 180 periodicals of general interest published in the United States and Canada. It is published twice a month from September through December and in March, April, and June. It appears monthly in January, February, May, July, and August. Library of Congress subject headings are used to organize materials. The quarterly and annual cumulations can expedite your search of this index. Selected terms on space policy used in the *Reader's Guide* include: Space, outer; Space astronomy; Space industries; Space processing; Space warfare.

Index To Legal Periodicals

The *Index* lists articles "of high quality and permanent reference value" in legal periodicals published in the United States, Canada, Great Britain, and other English language countries. The articles are indexed under author and subject. A complete list of subjects is included at the front of each bound volume. The primary search term is Space law.

NEWSPAPER ARTICLES

New York Times Index

The *New York Times Index* provides extensive abstracts for articles appearing in the *New York Times*. It is issued twice a month, with quarterly and annual cumulations. Consult "How to use the New York Times Index" in the index volume itself for guidance. Some useful terms include: Space, Astronautics, Space weapons (star wars), and Space shuttle.

Official Washington Post Index

The *Index* provides access to all substantial newsworthy items in the *Washington Post*, excluding wire service articles. It is issued monthly and cumulated annually. Some useful search terms include: Space, Astronomy, Space exploration, Astronautics, Satellites, Space weapons and Space station.

Wall Street Journal Index

The *Wall Street Journal Index* is issued monthly and has annual cumulations. The primary search term is Space exploration.

National Newspaper Index (microfilm)

National Newspaper Index indexes the *Christian Science Monitor*, *New York Times*, *Wall Street Journal*, *Los Angeles Times*, and *Washington Post*. References from the last five years are listed alphabetically by subject headings.

Other Newspaper Indexes

Bell & Howell Co. produces a set of indexes which list articles appearing in the *Boston Globe*, *Christian Science Monitor*, *Denver Post*, *Detroit News*, *Houston Post*, *Los Angeles Times*, *New Orleans Times-Picayune*, *San Francisco Chronicle*, *St. Louis Post Dispatch*, and *USA Today*. University Microfilms International produces monthly and annual indexes for the *Atlanta Journal*, *Atlanta Constitution*, *Chicago Tribune*, *Los Angeles Times*, and the *Minneapolis Star and Tribune*. In addition, many newspapers are indexed locally; ask a librarian about indexes to your local newspaper.

ONLINE DATABASES

Many libraries now have access to computerized versions of printed indexes. The information is stored in databases that can be accessed through personal computers. The advantages of using these computerized databases are search speed and flexibility; the disadvantages are the often high costs charged for access. Check with your local reference librarian to determine availability and costs of the systems listed below.

BRS

BRS is an online service providing primarily bibliographic information. The service offers access to information in the fields of science, social sciences, business, health and related areas. NTIS (National Technical Information Service) is available on BRS.

DIALOG

DIALOG Information Service is an online service that includes a wide variety of databases, ranging from newspaper and journal indexes through statistical references and airline information. Some of the indexes available on DIALOG include online versions of the *National Newspaper Index*, *Washington Post*, AP and UPI newswires, *Magazine Index* (with full-text of some articles). Several specialized aerospace databases as well as the National Technical Information Service are available on the Dialog system.

NEWSNET

NEWSNET includes comprehensive bibliographic data on more than 380 newsletters and other news and information services. Specific information on elements of the space policy debate topic may be found in the aerospace and aviation segment. Such sources as *Satellite Week*, *Space Business News*, *Space Calendar*, *Space Daily*, and *Space Station News* are available via NEWSNET.

NEXIS

NEXIS is an online search and retrieval service that contains the full text of many newspapers, including the *New York Times*, the *Washington Post*, and the *Christian Science Monitor*; full text of major wire services, including AP, UPI, and Reuters; and full text of a number of magazines, newsletters, and government publications.

VUTEXT and DataTimes

Both of these online services index local and regional newspapers for most of the major metropolitan areas in the United States.

WilsonLine

The H. W. Wilson Company, which publishes the *Reader's Guide* to Periodical Literature, along with a number of other indexes to journal literature, has its own online service. Of particular interest is the *Applied Science and Technology Index*.

CD-ROM DATABASES

Some libraries have installed CDL-ROM databases as an alternative to print and online indexes. CD-ROM is a technology that allows a great deal of information to be stored on a compact disk that can be read by a personal computer. A number of indexes are available in this format, allowing searching capabilities similar to those available with online services, but without the charge per hour. Some of the indexes available in this format include *Magazine Index*, and the Wilson indexes. Consult with your local reference librarian to determine whether this service is available in your area.

GOVERNMENT PUBLICATIONS

Federal Depository Library Program

This program makes Government publications available to 1400 designated depository libraries. In order to provide the greatest possible access to Government publications, depository libraries are located in each congressional district. Of this number, 50 have been designated as regional depositories. Fifty regional libraries assume the responsibility for retaining depository material permanently, and of providing inter-library loan and reference service for their regions. Copies of documents no longer available for sale by the Government can usually be found in regional Federal depository library collections. Each issue of the *Monthly Catalog of United States Government Publications* (see below) prints a current directory of these regional libraries. A directory of all depository libraries is available from: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Government Reports Announcements and Index

Government research reports are indexed in the *Government Reports Announcements and Index*, which is issued twice a month by the National Technical Information Service (NTIS). A keyword index lists significant words from titles. The *NTIS* index is available online through commercial systems.

Monthly Catalog of United States Government Publications

The *Monthly Catalog* lists documents issued by all branches of the Federal Government. The catalog has monthly, semiannual, and annual indexes, arranged by author, title, subject, keywords, and series/report title. It is an excellent tool for locating materials housed in depository libraries; it can also be used to obtain information about purchasing documents directly from the Superintendent of Documents at the U.S. Government Printing Office. The *Monthly Catalog* is available commercially, and through most libraries. The search terms used are the Library of Congress subject headings described in the section of this guide on books.

Treaties in Force: A list of treaties and other international agreements of the United States in force on January 1, 1989

This publication, which is compiled by the Treaty Affairs Staff, Office of the Legal Adviser, U.S. Dept. of State, "lists treaties and other international agreements of the United States on record in the Department of State on January 1, 1989 which had not expired by their terms or which had not been announced by the parties, replaced or suspended by other agreements."

Weekly Compilation of Presidential Documents

This publication contains statements, messages, and other Presidential materials released by the White House during the preceding week. There are weekly, quarterly, and annual published indexes. This information is also available online commercially. Public Papers of the Presidents of the United States is an annual compilation of Presidential Statements.

LEGISLATIVE INFORMATION

Congressional activities on U.S. policy regarding space policy and programs may be monitored by searching the following printed publications:

Congressional Quarterly Weekly Report

This periodical provides current information on congressional activities, the status and progress of current legislation, and major policy issues. Recent articles of particular importance are indexed on the back cover of each issue. Consult this index under the heading Science/Technology. Quarterly and annual indexes are also issued; you may find information under the headings Space policy and SDI. Cross references are also provided.

Congressional Quarterly also publishes an annual volume which cumulates material from the weekly reports. There is an index at the back of each volume, which uses similar subject headings.

National Journal

National Journal is a monthly publication containing articles on executive branch and congressional activities. Toward the end of each issue there is a page entitled "Recent Articles." Use this page as an abbreviated index, looking under the term Science and Technology. A semi-annual index is published which allows searching under more specific topics.

Congressional Record

The *Congressional Record* is an edited transcript of the activities on the floor of the U.S. House and Senate. An issue is published for each day that either chamber of Congress is in session. Subject and name indexes are published biweekly and cumulated annually. Search for information on this year's debate topic under Space sciences.

BILLS AND RESOLUTIONS

Major Legislation of the Congress

The *MLC* provides summaries of selected major legislation arranged by subject. It includes background on the issues and information on the content and status of major bills affecting that issue. The publication may be examined at a depository library, or purchased from the Government Printing Office. Search under the heading Science and technology.

Digest of Public General Bills and Resolutions

The *Digest* summarizes the essential features of public bills and resolutions, and any changes made in them during the course of the legislative process. Two cumulative issues are published during each session of Congress, and a final issue is published at the conclusion of the session. The *Digest* includes information on sponsors and cosponsors of legislation, identical bills, short titles, and subject indexes.

CIS Index

The *CIS Index* is produced by the Congressional Information Service, and contains abstracts of all congressional publications except the *Congressional Record*. The index is published monthly, and cumulated quarterly and annually. Each issue of the index is divided into both index and abstract portions. Search in the index section under topics such as: Space programs, Space commercialization, and Space weapons.

Congressional Index

The *Congressional Index*, published by the Commerce Clearing House, is a weekly looseleaf service providing content and status information for bills and resolutions pending in Congress. The progress of bills and resolutions is reported, from the introduction of the legislation to the final disposition.

STATISTICAL SOURCES

American Statistics Index (ASI)

The *American Statistics Index* indexes and describes the statistical publications of the U.S. Government, including periodicals, annuals, biennials, semi-annuals, and special publications. It provides access to statistical materials by subject, organization, name, issuing source, and title. The index is published monthly and cumulated annually. *ASI* is also available through commercial online systems.

Statistical Abstract of the United States: National Data Book and Guide to Sources

Published by the U.S. Department of Commerce, Bureau of the Census on an annual basis, this source includes pertinent statistical information under the subjects Space program and Space research and technology. This publication should be available in any depository library, as well as in the reference collections of most large public or academic libraries.

Statistical Reference Index

The *Statistical Reference Index* provides a guide and index to selected statistical reference material from non-Federal sources on a wide variety of topics. It includes the publications of trade, professional, and other non-profit associations and institutions, business organizations, commercial publishers, university and independent research centers, and State government agencies. Information can be accessed by subject, organization, name, issuing source, and/or title. The index is published monthly and cumulated annually.

AeroSpace Facts and Figures

This resource is issued every two years by the Aerospace Industries Association of America. It includes information about aircraft production, missile programs, space programs, research and development and other issues.

NASA Pocket Statistics

This resource is published and distributed annually by the Office of Headquarters Operations, Code D-1, National Aeronautics and Space Administration, Washington, D.C. 20546. It includes administrative and organizational information, summaries of space flight activity (including the NASA Major Launch Record), NASA procurement, and other data.

PART II: REFERENCE SOURCES ON SPACE POLICY

REFERENCE BOOKS

Aeronautics and space flight collections. Edited by Catherine D. Scott. New York, Haworth Press, c1985. 229 p.

Aeronautics and space report of the President: 1987 activities. Washington, National Aeronautics and Space Administration, 1989. 182 p.

This is the most recent in a series of reports with the same title and issued annually. Includes descriptive information about elements of the U.S. space program, interagency programs, and budgetary information.

The Air & space catalog: the complete sourcebook to everything in the universe. Edited by Joel Makower and Marilyn Fenichel. New York, Vintage Books, 1989.

This book will be available later in 1990.

Astronautics and cosmonauts: biographical and statistical data revised June 30, 1989; report prepared by the Congressional Research Service, Library of Congress transmitted to the Committee on Science, Space, and Technology, U.S. House of Representatives, 101st Congress, 1st session. Washington, G.P.O., 1989. 447 p.

At head of title: Committee Print, Serial I.

"This volume . . . updates the last edition, published in 1985 . . . . Part I covers all participants in U.S. space missions . . . . Part II details participants on Soviet missions . . . . Part III contains a series of comparative tables on U.S. and Soviet spaceflights."

Astronomy from space: Sputnik to space telescope. Edited by James Cornell and Paul Gorenstein. Cambridge, Mass., MIT Press, c1983. 248 p.

A "collection of articles by leading experts in the field, covering everything from planetary astronomy to space astronomy and beyond."

A Bibliography on the search for extraterrestrial intelligence. By Eugene F. Mallove and others. [Washington] National Aeronautics and Space Administration, Scientific and Technical Information Office; [Springfield, Va., for sale by the National Technical Information Service [1978] 132 p. (NASA Reference publication 1021)

Bilstein, Roger E.

Orders of magnitude: a history of the NACA and NASA, 1915-1990. Washington, National Aeronautics and Space Administration, Science and Technical Information Division, 1989. 167 p.

"Concise history of the National Advisory Committee for Aeronautics (NACA) and its successor agency, the National Aeronautics and Space Administration (NASA)."

Blashfield, Jean F.

Aerospace bibliography. Washington, U.S. National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1982. 140 p.

Curtis, Anthony R.

Solar system handbook. Woodsboro, Md., Arcsoft Publishers, 1990.

This work will be available later in 1990.

Curtis, Anthony R.

Space almanac: facts, figures, names, dates, places, lists, charts, tables, maps covering space from earth to the edge of the universe. Woodsboro, Md., Arcsoft, c1989. 955 p.

Furniss, Tim.

Space flight: the records. Enfield, Middlesex, Guinness Books; New York, Distributed by Sterling Pub. Co., c1985. 168 p.

The Home planet. Edited by Kevin W. Kelley for the Association of Space Explorers. Reading, Mass., Addison-Wesley; Mowcow, Mir Publishers, c1988. 256 p.

The Illustrated encyclopedia of space technology: a comprehensive history of space exploation. New York, Harmony Books, 1981. 289 p.

Traces the history of the conquest of space, and considers such concepts as space colonies, factories in space, satellite solar power stations and bases on the Moon. Contains information on Soviet and Chinese launch vehicles.

Jane's spaceflight directory. Surrey, UK; Alexandria, Va., Jane's Information Group.

This work is issued every two years. It provides comprehensive information about space programs, international efforts, military space efforts, launchers, and other aspects of space studies.

Logsdon, John M.

The decision to go to the moon: Project Apollo and the national interest. Cambridge, Mass., MIT Press, 1970. 187 p.

Magill's survey of science: space exploration series. Edited by Frank N. Magill. Pasadena, Calif., Salem Press, c1989. 5 v.

Contents.--Volume 1: A Food diet for space travel.--Volume 2: The French space program.--The Mercury Project.--Volume 3: The Development of the Mercury Project-Soyuz 6, 7, 8.--Volume 4: Soyuz--Space planes.--Volume 5: The Development of spacesuits-Z.--Index.

Mallove, Eugene F. Forward, Robert L.

Bibliography of interstellar travel and communication. Journal of the British Interplanetary Society, v. 27, Dec. 1974: 921-943; v. 28, Mar. 1975: 191-219; June: 405-434; v. 29, July-Aug. 1976: 494-517.

Published in 4 parts, the bibliography contains over 1000 articles, books, and reports discussing the problems of interstellar travel and communication. Arrangement is by eight major categories and subdivisions.

McDonough, Thomas R.

Space, the next twenty-five years. New York, Wiley, c1989.

This work will be available later in 1990.

McDougall, Walter A.

The heavens and the Earth. New York, Basic Books, c1985. 555 p.

Partial contents.--The Genesis of Sputnik.--Presents a detailed history of the early space programs of the U.S. and Soviet Union.

McGraw-Hill encyclopedia of astronomy. Sybil P. Parker, editor-in-chief. New York, McGraw-Hill, 1983. 450 p.

Moore, Patrick.

Space. [1st ed. in the U.S.A.] Garden City, N.Y., published for the American Museum of Natural History [by] Natural History Press, 1969 [c1968]. 216 p.

NASA historical data book. Washington, D.C., Scientific and Technical Information Division, National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1988. 3 v. (NASA historical series; NASA SP, 4012)

Contents.--Volume 1: Republication of the NASA historical data book, 1958-1968, by Jane Van Nimmen and Leonard C. Bruno.--Volume 2: Programs and projects, 1958-1968, by Linda Newman Ezell.--Volume 3: Programs and projects 1969-1978, by Linda Newman Ezell.

This three-volume set provides a comprehensive summary of NASA's resources (personnel, budgets, and facilities) and its aeronautical and space programs and projects for the period 1958-1978. Summary chapters include brief narrative accounts of each program and project, as well as tables and charts summarizing technical, management, and funding data. NASA programs covered include launch vehicles, manned spaceflight, space science and applications, advanced research and technology, and tracking and data acquisition.

The NASA program in the 1990s and beyond. Washington, U.S. Congressional Budget Office, 1988. 85 p.

Newell, Homer E.

Beyond the atmosphere: early years of space science. Washington, Scientific and Technical Information Branch, National Aeronautics and Space Administration; for sale by the Supt. of Docs., G.P.O., 1980. 497 p. (NASA history series; 4211)

Out of this world: an illustrated guide to space technology and exploration. New York, Arco, c1985. 118 p.

Plant, Malcolm.

Dictionary of space. Harlow, Essex [England] Longman, 1986. 270 p.

The RAE table of earth satellites 1957-1982, 2nd edition, compiled at the Royal Aircraft Establishment, Farnborough, Hants, England. London, MacMillan Publishers, 1983. 753 p.

The Table is a chronological list of the 2,389 launches of satellites and space vehicles between 1975 and the end of 1982, giving the name and international designation of each satellite and its associated rockets, date of launch, lifetime, mass, shape, dimensions and at least one set of orbital parameters.

Ride, Sally K.

Leadership and America's future in space; a report to the administrator of the National Aeronautics and Space Administration. Washington, The Administration, 1987. 63 p. LRS87-9251

"In response to growing concern over the posture and long-term direction of the U.S. civilian space program, NASA Administrator Dr. James Fletcher formed a task group to define potential U.S. space initiatives, and to evaluate them in light of the current space program and the nation's desire to regain and retain space leadership." Of the four initiatives considered, 1) Mission to Planet Earth, 2) Exploration of the Solar System, 3) Outpost on the Moon, and 4) Humans to Mars, the task group recommended exploration of the Moon and human exploration of Mars.

Shelton, William Rory.

American space exploration: the first decade. Boston, Little, Brown, 1967. 367 p.

Should the U.S. Federal Government significantly increase the exploration and/or development of space beyond the earth's mesosphere? Intercollegiate debate topic, 1984-1985, pursuant to Public Law 88-246. Compiled by the Congressional Research Service, Library of Congress. Washington, G.P.O., 1984. 1616 p. (Document, House, 98th Congress, 2nd session, no. 98-257)

Space science in the twenty-first century: imperatives for the decades 1955-2015. Washington, prepared by the Commission on Physical Sciences, Mathematics, and Resources, National Research Council. Washington, National Academy Press, 1988. 7 v.

Contents.--Overview: report of the Study Steering Group, Space Science Board.--Astronomy and astrophysics, prepared by the Task Group on Astronomy and Astrophysics, Space Science Board.--Life sciences, prepared by the Task Group on Life Sciences, Space Science Board.--Mission to Planet earth, prepared by the Task Group on Earth Science, Space Science Board.--Planetary and lunar exploration, prepared by the Task Group on Planetary and Lunar Exploration, Space Science Board.--Solar and Space physics, prepared by the Task Group on Solar and Space Physics, Space Science Board.--Fundamental physics and chemistry, prepared by the Task Group on Fundamental Physics and Chemistry, Space Science Board.

Space science series. Edited by Mildred Shapley Matthews. Tucson, Ariz., University of Arizona Press, 1982-89. 11 v.

Contents.--Satellites of Jupiter.--Comets.--Venus.--Planetary rings.--Saturn.--Protostars and planets II.--Galaxy and the solar system.--Satellites.--Meteorites and the early solar system.--Origin and evolution of planetary and satellite atmospheres.--Asteroids II.

Space handbook. Prepared by Air Command and Staff College; edited by Curtis D. Cochran, Dennis M. Gorman, Joseph D. Dumoulin. 12th revision. Maxwell Air Force Base, Ala., Air University Press, Air University; Washington, for sale by Supt of Docs., G.P.O, 1985. 1 v. (various pagings)

Space law: selected selected basic documents. Prepared at the request of Howard W. Cannon, chairman, Committee on Commerce, Science, and Transportation, United States Senate. 2nd ed. Washington, G.P.O., 1978. 600 p.

At head of title: 95th Congress, 2nd session. Committee print.

The first edition was published in 1976 by the Committee on Aeronautical and Space Sciences, United States Senate. A new edition will be available later in 1990

Stares, Paul B.

The militarization of space: U.S. policy, 1945-1984. Ithaca, N.Y., Cornell University Press, 1985. 334 p.

Taillefer, Yves.

A glossary of space terms. Paris, European Space Agency, 1982. 432 p.

"ESA-SP-1011"

Two hundred years of flight in America: a bicentennial survey. Edited by Eugene M. Emme. San Diego, Calif., Univelt, c1977. 310 p. (AAS history series, v. 1; American Astronautical Society publication)

"Proceedings of a symposium held at the National Air and Space Museum, Nov. 4, 1976."

U.S. National Aeronautics and Space Administration. The Office of Exploration. Beyond earth's boundaries: human exploration of the solar system in the 21st century; 1988 annual report to the administrator. Washington, National Aeronautics and Space Administration, 1988. 51 p. LRS88-15836

The Office of Exploration was established as "a focal point to fund, lead, and coordinate studies of human exploration of the solar system. Building on the two initiatives featuring piloted exploration--Outpost on the Moon and Humans to Mars--the Office now heads a NASA-side effort, the goal of which is to identify viable alternatives and provide recommendations for an early 1990s national decision on a focused program of human exploration."

U.S. National Aeronautics and Space Administration.
Long-range program plan--1989. Washington, The Administration, 1989. 1 v. in various pagings.

"This plan outlines the direction of NASA's future activities by discussing goals, objectives, current programs, and plans for the future. Normally an annual event, the plan was not published for two years (the last one was the 1986 Long-Range Program Plan) because of the Challenger disaster and continuing budget uncertainties. The 1989 plan is consistent with national policy for both space and aeronautics, and with the FY 1989 budget that the President submitted to Congress in February 1988."

U.S. National Commission on Space.
Pioneering the space frontier. New York, Bantam Books, 1986. 211 p.

"The National Commission on Space proposes a future-oriented civilian space agenda with three mutually-supportive thrusts: advancing our understanding of our planet, our Solar System, and the Universe; exploring, prospecting, and settling the Solar System; and stimulating space enterprises for the direct benefit of the people on Earth . . . . To accomplish them economically, the Nation must make a long-range commitment to two additional thrusts: advancing technology across a broad spectrum to assure timely availability of critical capabilities; and creating and operating systems and institutions to provide low-cost access to the space frontier."

U.S. President.
For statements on space policy by Presidents Eisenhower, Kennedy, Johnson, Nixon, Ford, Carter, Reagan and Bush consult the Public Papers of the Presidents and Weekly Compilation of Presidential Documents. Check the Government Publications section of this guide for search hints.

VonBraun, Wernher. Ordway, Frederick I. III.
Space travel: a history. 4th ed. New York, Harper & Row, c1985. 308 p.

Weber, Ronald.
Seeing earth: literary responses to space exploration. Athens, Ohio, Ohio University Press, c1985. 138 p.

The World Book of space exploration. Chicago, World Book, c1989. 2 v.

INDEXES, ABSTRACTS, AND CONTENTS SERVICES

Aerospace Database

This is the online version of two printed publications: *International Aerospace Abstracts (IAA)* and *Scientific and Technical Aerospace Reports (STAR)*. It is a comprehensive engineering and technology information resource providing worldwide bibliographic coverage of published and unpublished scientific and technical literature. The Aerospace Database is co-produced by the American Institute of Aeronautics, Technical Information Service (AIAA/TIS) and the National Aeronautics and Space Administration, Scientific and Technical Information Branch (NASA/STIB). *Aerospace Database* in available on Dialog.

Air University Library Index to Military Periodicals

This is a subject index to a significant articles, news items, and editorials appearing in 78 English language military and aeronautical periodicals not indexed in readily available commercial indexing services.

Applied Science & Technology Index

This is a subject index to articles appearing in science and engineering journals. The *Index* is issued monthly and cumulated quarterly and annually. This index is also available in an on-line format via Wilsonline.

Arms Control Reporter

This is a published monthly by the Institute for Defense and Disarmament Studies. The *Reporter* presents the status, analysis and chronology on treaty negotiations on such topics as Anti-ballistic Missile Treaty, SALT II, chemical weapons, antisatellite systems, and nuclear non-proliferation. The chronology pages give day-to-day coverage of issues compiled from news services around the world.

Aviation/Aerospace Online

This is a commercial data base available from McGraw-Hill, 1156 15th Street, N.W., Washington, D.C. 20005, 202/822-4675. It contains the same information as *Aerospace Daily* and can be used to search for defense and space programs, budgets, and technical and industrial trends. The system contains current and retrospective materials. It has two sections: *Aerospace Daily* abstract service which has daily on-line delivery of 2-3 line abstracts and full text call-up capabilities; and *Aerospace Intelligence Retrieval* which includes *Aviation Week and Space Technology*; *Aerospace Daily*, *Commercial Space News*; *Military Space News*; *Performance Materials*; NASA Budgets; biographies of top level NASA personnel; and information on commercial space issues. There is a fee associated with this data base.

Business Periodicals Index

Articles from over 300 business periodicals are listed in this index. It is published monthly, except for August, and a bound cumulation is issued each year. A wide range of business publications, such as the *Economist* and *Barrons*, are indexed here. Use Library of Congress subject headings to search, along with the cross-references provided in the index.

International Aerospace Abstracts

This is published semimonthly by the American Institute of Aeronautics and Astronautics. *IAA* covers published literature in periodicals and books; meeting papers and conference proceedings issued by professional and academic organizations; and translations of journals and articles in aeronautics and space science and technology. Indexes are cumulated semiannually and annually.

NASA Spacelink

This is a collection of NASA information and educational materials on such issues as space exploration before the space shuttle; space exploration beyond the space shuttle, NASA and its centers, NASA educational services, space spinnoffs, and other NASA related topics. The data is stored on a computer at the Marshall Space Flight Center in Huntsville, Alabama. The system may be accessed over regular telephone lines. It is designed to communicate with a wide variety of computers and modems, especially those most commonly found is classrooms and homes. NASA Spacelink is free, but there is a charge for long distance phone calls. The phone number for Spaceline is 205/895-0028; data format 8-None-1.

NTIS (National Technical Information Service)

This database is available commercially online. NTIS consists of government sponsored research, development, and engineering prepared by Federal agencies, their contractors or grantees. Through this system, unclassified, publicly available reports such agencies as NASA, Department of Commerce, the Defense Department and others are made available. The database includes materials from both the hard and soft sciences, including material on technological applications, business procedures and regulatory matters. NASA document accessions numbers are used in NTIS and copies of NASA studies may be ordered through NTIS.

Science Citation Index

This is published quarterly with an annual cumulation. The *Index* provides access to related articles by indicating sources in which a known article by a given author has been cited. This index is available commercially online as *Scisearch*.

Scientific and Technical Aerospace Reports (STAR)

This is published by NASA on the 8th and 23rd of every month. Cumulative index volumes are published annually. STAR announces current publications on all aspects of aeronautics and space research and development, supporting basic and applied research, and applications. Included in STAR are NASA contractor, and NASA grantee reports, reports by U.S. Government agencies, domestic and foreign institutions, NASA owned patents and patent applications, and dissertation theses. Specialized search terms are listed in the NASA thesaurus.

Social Science Citation Index

This index, which covers hundreds of journals, is issued quarterly and annually. Unlike most other indexes, it does not have standard subject headings; instead, key words from an article's title are listed in the Permuterm Subject Index, and full citations are then provided in the Source Index.

Social Sciences Index

This index, which is published quarterly and cumulated annually, gives author and title access to articles from a range of journals in the social sciences. Some of the public policy journals include articles on space policy. Use Library of Congress subject headings, as well as the cross-references provided in the index, to search for information.

SELECTED PERIODICALS

Magazines and Journals on Space Policy:

Ad Astra
Air & Cosmos (weekly in French; monthly in English)
Air & Space
Air University Review
Astronautics & Aeronautics
Astronomy
Astronomy & Astrophysics
Aviation Week and Space Technology
Earth, Moon, & Planets
ESA Journal
Final Frontier
Flight International
Interavia
Journal of Space Law
Journal of the British Interplanetary Society
Sky and Telescope
Space Calendar
Space Commerce Bulletin
Space Markets (Interavia)
Space News
Space Policy
Space World
Spaceflight

Magazines and Journals on Scientific Issues:

American Scientist
Discover
IEEE Spectrum
Issues in Science and Technology
Nature
Omni
Physics Today
Popular Science
Science
Science and Global Security
Science and Public Policy
Scientific American
The Sciences

Magazines and Journals on Public Policy Issues:

American Spectator
Brookings Review
Futurist
Global Affairs
National Interest
Policy Review
Public Interest
Washington Quarterly
Wilson Quarterly

Newsletters:

Aerospace Daily
Defense Daily
Military Space
Satellite News
Soviet Aerospace
Space Business News
Space Commerce Bulletin
Space Station News and Advanced Space Technology

FEDERAL GOVERNMENT AGENCIES

This list includes the names and addresses of some Federal agencies which may be able to provide information to researchers on issues pertaining to space policy.

Elementary and Secondary Programs
Educational Affairs Division
Office of External Affairs
600 Independence Avenue, S.W.
National Aeronautics and Space Administration
Washington, D.C. 20546
202/453-8386

The National Aeronautics and Space Administration "conducts research for the solution of problems of flight within and outside the Earth's atmosphere and develops constructs, tests, and operates aeronautical and space vehicles. It conducts activities required for the exploration of space with manned . . . [human and robotic] vehicles and arranges for the most effective utilization of the scientific and engineering resources of the United States with other nations engaged in aeronautic and space activities for peaceful purposes."

NASA has an organization of regional centers designed to answer requests regarding information:

IF YOU LIVE IN:	*NASA REGIONAL OFFICE*
Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming	Educational Programs Branch Mail Stop T025 NASA Ames Research Center Moffett Field, CA 94035 Phone: (415)694-5543
Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hamshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont	Educational Programs Public Affairs Office (130) NASA Goddard Space Flight Center Greenbelt, MD 20771 Phone: (301)286-7207
Colorado, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas	Public Affairs Office (AP-4) NASA Johnson Space Center Houston, TX 77058 Phone: (713)483-8624
Florida, Georgia, Puerto Rico, Virgin Islands	Education and Awareness Branch Mail Code PA-EAB NASA Kennedy Space Center Kennedy Space Center, FL 32899 Phone: (407)867-4444
Kentucky, North Carolina, South Carolina, Virginia, West Virginia	Educational Office Mail Stop 154 NASA Langley Research Center Hampton, VA 23665-5225 Phone: (804)864-3312
Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	Educational Services Office Mail Stop 7-4 NASA Lewis Research Center 2100 Brookpark Road Cleveland, OH 44135 Phone: (216)433-5583

IF YOU LIVE IN:	*NASA REGIONAL OFFICE*
Alabama, Arkansas, Iowa, Louisiana, Missouri, Tennessee	Public Affairs Office (CA20) NASA Marshall Space Flight Center Marshall Space Flight Center, AL 35812 Phone: (205)544-6527
Mississippi	Education Office NASA John C. Stennis Space Center Stennis Space Center, MS 39529 Phone: (601)688-1957
The Jet Propulsion Laboratory (JPL) serves inquiries related to space and planetary exploration and other JPL activities.	Education Office Mail Code 180-205 Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109 Phone: (818)354-8592

National Air and Space Museum
Seventh Street and Independence Avenue, S.W.
Washington, D.C. 20560
202/357-2491

"Created to memorialize the development of aviation and space flight, the museum collects, displays, and preserves aeronautical and space flight artifacts of historical significance as well as documentary and artistic materials related to air and space. The exhibitions and study collections record human conquest of the air from its tentative beginnings to recent achievements by high altitude aircraft, guided missiles, rockets, satellites, and manned space flight. The principal areas in which work is concentrated include flight craft of all types, manned and unmanned, space flight vehicles, and propulsion systems."

OASD (PA)
Department of Defense
Directorate for Public Correspondence
RM 2E 777, The Pentagon
Washington, D.C. 20301-1400
202/697-6462

The Directorate for Public Correspondence will respond to requests for information on the Strategic Defense Initiative and military space programs.

Department of Transportation
Office of Commercial Space Transportation
400 Seventh Street, S.W.
Washington, D.C. 20590
202/366-2937

"The primary responsibility of the Office of Commercial Space Transportation is to promote private-sector investment in an operation of expendable launch vehicles, which are the unmanned booster rockets that place satellites in orbit. The Office provides the focal point within the Federal Government for licensing private-sector launch activities and for formulating and implementing consistent policies that enable the American launch vehicle industry to compete in both the domestic and international markets. Educational initiatives are also being formulated.

Office of Space Commerce
Room 7060
Department of Commerce
14th Street and Constitution Avenue, N.W.
Washington, D.C. 20230
202/377-8125

"The Office of Space Commerce (OSC) was established in the Office of The Deputy Secretary of Commerce. OSC has four main responsibilities: to act as the principle unit for coordinating space-related issues, programs, and initiatives within the Department; to represent the Department on the National Space Council at the Working Group level; to participate in international negotiations on trade relating to space technology; and, to encourage the export of U.S. space technology except in the case of sensitive technology transfer."

National Space Council
The White House
Washington, D.C.
202/395-6175

This office, which provides staff support to the President and Vice President, plans and coordinates U.S. space policy. The functions are detailed in P.L. 100-684, which established the National Space Council. The agency's annual report will be available in depository libraries later in 1990.

UNITED STATES GOVERNMENT PRINTING OFFICE
SUPERINTENDENT OF DOCUMENTS
WASHINGTON, D.C. 20402

SB-043

PUBLICATIONS RELATING TO THE 1990-91 HIGH SCHOOL DEBATE TOPIC

Resolved: Outer Space: What Should Be the United States Government Policy Toward the Region Beyond Earth's Atmosphere?

* *

Accessing Space: A Catalogue of Process, Equipment and Resources for Commercial Users. *Provides information about the equipment and facilities that are being used and developed for commercial space applications, especially in the areas of microgravity research and remote sensing.* 1988: 206 p.; ill.
S/N 033-000-01029-0 $11.00

Apollo Expeditions to the Moon. 1975: 313 p.; ill. 1985-repr. Clothbound. NAS 1.21:350
S/N 033-000-00630-6 13.00

Astronautics and Aeronautics, 1978: A Chronology. *Consists of a month by month chronology of various events occurring in the National Aeronautics and Space Administration during 1978. Also includes the following appendices: Satellites, Space Probes, and Manned Spaceflights, 1978; Major NASA Launches, 1978; NASA Sounding Rocket Launches, 1978; Abbreviations; and Index.* 1986: 402 p.; ill.
S/N 033-000-01010-9 13.00

Best We Can Be. *Documents America's record in space flight and salutes the people who made it happen. Includes chronological lists of the Mercury, Gemini, Apollo, skylab, and space shuttle missions, through STS-27, Fall 1988. The chronology provides purposes for the pre-shuttle flights, names of the crew members, reproductions of the official mission decals, and date(s) of each launch and flight. Also provides information about the work of major NASA contractors.* 1988: 24 p.; ill.
NAS 1.2:B 46 S/N 033-000-01037-1 2.00

Beyond Earth's Boundaries: Human Exploration of the Solar System in the 21st Century, 1988 Annual Report to the Administrator. *Includes sections on four case studies: Human expeditions to Phobos, one of the moons of Mars; human expeditions to Mars; lunar observatory; and lunar outpost to early Mars evolution. Illustrated with color drawings, photographs, and charts.* 1989: 51 p.; ill.
NAS 1.1/5:988 S/N 033-000-01045-1 4.25

Commercial Use of Space: A New Economic Strength for America. *Describes space commerce, its benefits for the Nation, and NASA's role in developing it. Provides information on four examples of ways in which industry can use space: satellite communications; earth and ocean observations; materials research and processing; and space transportation and industrial services.* 1989: 24 p.; ill.
S/N 033-000-01035-4 2.25

Evolution of Complex and Higher Organisms: A Report Prepared by the Participants of Workshops Held at NASA Ames Research Center, Moffett Field, California, July 1981, January 1982, and May 1982. 1985: 112 p.; ill. NAS 1.21:478
S/N 033-000-00951-8 8.50

Exploring the Living Universe: A Strategy for Space Life Sciences. *Recommends goals, objectives, and priorities for: the overall life sciences program; the sub-programs of human space flight, gravitational biology, and planetary biological research; flight programs; and program administration.* 1988: 231 p., ill.
NAS 1.2:L 62 S/N 033-000-01024-9 $15.00

Far Travelers: The Exploring Machines. *Provides a historical overview of NASA's unmanned spacecraft, from its early development through completion of the Pioneer program in the late 1970's.* 1985: 267 p., ill. Clothbound.
NAS 1.21:480 S/N 033-000-00957-7 17.00

Geology of the Terrestrial Planets. *Outlines the geologic history of the terrestrial planets; the Earth, Mercury, Venus, and Mars in light of recent exploration and a revolution in geological thought. Geological features of the Moon, asteroids, and comets are also discussed.* 1984: 325 p.; ill., 25 plates. Clothbound.
NAS 1.21:469 S/N 033-000-00900-3 16.00

Halley's Comet: A Bibliography. 1984: 585 p. Clothbound.
LC 33.9/3:H 15 S/N 030-000-00158-3 26.00

How We Get Pictures From Space. *Describes the scanning and imaging technologies used by the Voyager spacecraft. Also includes a chronological listing of photographs produced by unmanned spacecraft from 1959-1977.* 1987: 11 p.; ill. revised ed.
NAS 1.20:NF-151/987 S/N 033-000-01005-2 1.00

International Cometary Explorer Wallsheet. *Depicts the International Cometary Explorer spacecraft. Also includes a brief pictorial description of the ICE's first and second missions, the Comet Giacobini-Zinner, and NASA's guiding and tracking methods.* 1985: Poster, 37x41 in.
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Into the Thermosphere: The Atmosphere Explorers. *The thermosphere includes the region in which the transition from air to space begins. This publication discusses NASA's study of the upper atmosphere and the satellites and spacecraft that have been used in this research.* 1987: 183 p.; ill. Clothbound.
NAS 1.21:490 S/N 033-000-01013-3 14.00

Living Aloft: Human Requirements for Extended Spaceflight. *Identifies the psychological and social problems that may be associated with future space missions and explores possible solutions.* 1985: 432 p.; ill.
NAS 1.21:483 S/N 033-000-00949-6 14.00

Living and Working in Space: A History of Skylab. *Traces the history of the Skylab program, from its conception in 1963 through its demise in 1983.* 1983: 462 p.; ill. Clothbound.
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Living in Space. *Contains classroom and home activities designed to encourage student interest in space science. Issued with perforations.*

Book 1: Levels A, B, C. *Includes activities on: food; clothing; health; housing; communications; working in space; and information on NASA Teacher Resource Centers.* 1987: 66 p.; ill., 8 plates. looseleaf.
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Book 2: Levels D, E, F. *Includes lesson objectives, vocabulary, motivation, activity descriptions, and additional activities for school or home on: food; housing; clothing; health; communications; working in space; and information on NASA Teacher Resource Centers.* 1987: 68 p.; ill., 6 plates. looseleaf.
S/N 033-000-01001-0 $ 4.75

Magellan: The Unveiling of Venus. *Discusses the radar imaging spacecraft Magellan and its mission to study the planet Venus.* 1989: 25 p.; ill.
NAS 1.12/7:400-345 S/N 033-000-01044-3 2.00

Meeting With the Universe: Science Discoveries From the Space Program. *Written for curious non-scientists, this colorful book presents a history of space exploration by NASA, by government agencies, and by industries. Includes chapters on the climb into space; the new worlds, the sun and earth in space; beyond the solar system; and the human element.* 1981: 231 p.; ill.
NAS 1.19:177 S/N 033-000-00836-8 14.00

NASA Activities. (Bimonthly.) *Contains general and scheduled activities of* NASA. Subscription price: Domestic - $10.00 a year; Foreign - $12.50 a year. Single copy price: Domestic - $2.00 a copy; Foreign - $2.50 a copy. (NACT) (File Code 2M)
NAS 1.46: S/N 733-001-00000-3

New Space Network: The Tracking and Data Relay Satellite System. 1986: 28 p.; ill.
NAS 1.19:251 S/N 033-000-00988-7 2.75

On Mars: Exploration of the Red Planet. 1958-1978. *Traces the history of NASA's exploration of Mars, focusing on the Mariner, Voyager and Viking spacecraft programs.* 1984: 549 p.; ill.
NAS 1.21:4212 S/N 033-000-00869-4 20.00

On Space Warfare: A Space Power Doctrine. *Defines the belief structures, or doctrines, on both sides of the "Star Wars" defense debate. Analyzes whether space power should have the same military connotation as air power and sea power, and if there should be such things as space forces.* 1988: 165 p.
S/N 008-070-00608-1 7.00

Other Worlds From Earth: The Future of Planetary Astronomy, A Report. *Reports on the goals and objectives for Earth-orbital planetary astronomy and ground-based and airborne planetary astronomy. Includes recommendations for future research. Also provides a concise two-page list of "Planetary Astronomy Discoveries and Advances During the Last Twenty-Five Years." Contains many color pictures and a few graphs and diagrams.* 1989: 98 p.; ill.
NAS 1.2:P 69/4 S/N 033-000-01052-4 7.00

Our Planets at a Glance. *Describes interplanetary exploration conducted by Viking, Pioneer, Voyager, and Mariner spacecraft.* 1982: 16 p.; ill.
NAS 1.20:NF-134 S/N 033-000-00859-7 2.75

Pioneer Venus. *Describes the Pioneer Venus mission, the knowledge and understanding of Venus as a planet, and the Venus environment that it revealed.* 1983: 262 p.; ill.
NAS 1.21:461 S/N 033-000-00873-2 11.00

Planetary Exploration Through Year 2000:

Core Program. 1983: 167 p.; ill.
NAS 1.2:Ex 7/2 S/N 033-000-00882-1 $ 7.00

Core Program: Mission Operations, A Report by the Solar System Exploration Committee of the NASA Advisory Council. 1986: 55 p.; ill. NAS 1.2:Ex 7/3 S/N 033-000-00993-3 4.00

Scientific Rationale. 1988: 88 p.; ill.
NAS 1.2:Ex 7/4 S/N 033-000-01038-9 7.00

Round Trip to Orbit: Human Spaceflight Alternatives, Special Report. *Examines technologies and systems for transporting astronauts and scientists to and from low-Earth orbit, and explores some of the policy choices that Congress faces in the critical aspect of our space program. Analyzes ways to make the space shuttle safer and discusses proposed systems to replace the shuttle. Includes chapters on advanced rockets, the National Aero-Space Plane, and escape and rescue vehicles.* 1989: 128 p.; ill.
Y 3.T 22/2:2 Or 1 S/N 052-003-01155-7 5.50

Sapping Features of the Colorado Plateau: A Comparative Planetary Geology Field Guide. *Presents papers that examine the role of groundwater sapping in producing valley networks on Mars and in the analogous environment on Earth, the Colorado Plateau. The Colorado Plateau includes parts of Utah and Arizona.* 1988: 116 p.; ill. NAS 1.21·491 S/N 033-000-01027-3 6.00

Science in Orbit: The Shuttle and Spacelab Experience, 1981-1986. *Discusses research projects conducted by the Spacelab aboard the space shuttle. Research areas include: life sciences; materials science; solar physics; space plasma physics; atmospheric science; earth observations; and astronomy and astrophysics. Contains color photographs and an index.* 1988: 132 p.; ill. Clothbound.
NAS 1.2:Or 1/3 S/N 033-000-01039-7 16.00

Sentinels in the Sky: Weather Satellites. *Discusses how weather satellites are used in: predicting severe storms; estimating rainfall; search and rescue projects; volcanic monitoring; fire detection; oceanography; vegetation index mapping; and tracking schools of fish, eggs, and larvae. Also includes sections on GOES (Geostationary Operational Environmental Satellites), future plans, and definitions. Contains full color photographs.* 1988: 16 p; ill.
NAS 1.20:NF-152 (s) S/N 033-000-01016-8 1.50

SETI: Search for Extraterrestrial Intelligence. *Tries to answer the questions: Are we alone in the universe? Describes a research effort by NASA to use high speed computer technology and sensitive modern telescopes to conduct a systematic search for radio signals generated by distant technology.* 1989: 32 p.; ill.
NAS 1.83:114 S/N 033-000-01059-1 3.75

Space Commerce: An Industry Assessment. *Identifies existing and potential worldwide markets for space-related goods and services, focusing on five major areas: space transportation; satellite communications; satellite remote sensing; space-based industrial facilities; and materials research and processing in space.*
1988: 142 p. C 1.2:Sp 1 S/N 003-000-00655-7 7.00

Space Handbook. *Serves as a reference source on the physical laws and principles of the outerspace environment and provides background on the evolution of space policy and doctrine.* 1985: 364 p.; ill. revised ed. D 301.26/6-8:Sp 1/985 S/N 008-070-00569-7 $13.00

Space Mathematics: A Resource for Secondary School Teachers. *Provides high school mathematics teachers with materials illustrating the uses of mathematics on NASA's space programs.* 1986: 192 p.; ill. NAS 1.2:M 42 S/N 033-000-00992-5 8.50

Space Pioneers and Where They Are Now. 1987: 25 p.; ill. NAS 1.19:264 S/N 033-000-01003-6 1.75

Space Shuttle: The Journey Continues. *Written before the successful Discovery space shuttle flight in the fall of 1988, this publication discusses the benefits of continuing to explore space with the shuttle. Includes a list of the first 25 shuttle flights from 1981 to 1986, along with the names of their orbiters and payloads. Also discusses the recovery and improvement of the shuttle since the Challenger tragedy in 1986 and the plans for future shuttles. Illustrated with color photographs and drawings.* 1988: 24 p.; ill. NAS 1.2:Sh 9/14 S/N 033-000-01026-5 4.50

Space Shuttle: The Renewed Promise. *Provides details on the history of the space shuttle, from the study phase in 1964 through the successful launch of STS 26 aboard the Discovery Space Shuttle in September 1988. Includes chronologies and lists of achievements of the first 24 flights. Also discusses plans for longer missions and for the Freedom Space Station. Illustrated with drawings and color photographs.* 1989: 24 p.; ill. NAS 1.75:521 S/N 033-000-01034-6 2.00

Space Station: A Research Laboratory in Space. *Discusses the plans for and progress in the development of a space station for the 1990s. Canada, Japan, and countries of Western Europe are cooperating in the space station's development. The space shuttle is expected to be the main transportation system to the space station.* 1988: 16 p. S/N 033-000-01025-7 1.50

Space Station: A Step Into the Future. 1987: 8 p.; ill. NAS 1.75:510 S/N 033-000-01018-4 1.00

Space Telescope. *Traces the historical and technological development of the Space Telescope which was launched with the Space Shuttle in 1985.* 1983: 64 p.; ill. NAS 1.19:166 S/N 033-000-00862-7 5.50

Spacelab: An International Success Story. *Provides a chronological narrative about the development of the spacelab from 1967-1985.* 1987: 570 p.; ill. Clothbound. S/N 033-000-01012-5 33.00

Star Splitters: The High Energy Astronomy Observatories. 1984: 191 p.; ill. Clothbound. NAS 1.21:466 S/N 033-000-00907-1 12.00

Status and Future of Lunar Geoscience. *Describes past and present lunar geoscience research projects undertaken by NASA. Also includes a discussion of future areas of lunar research, emphasizing low cost methods.* 1986: 54 p.; ill. NAS 1.21:484 S/N 033-000-00997-6 4.25

Viking Orbiter Views of Mars. 1980: 182 p.; ill., stereo viewer in pocket. Clothbound. NAS 1.21:441 S/N 033-000-00795-7 11.00

Viking, The Exploration of Mars. *Describes the earlier exploration of Mars by the Mariner spacecrafts and more recently exploration by the Viking spacecrafts missions. Also contains information on: the search for life on Mars; physical characteristics; and Viking instruments.* 1984: 56 p.; ill.
NAS 1.19:208 S/N 033-000-00915-1 $ 4.50

Voyage to Jupiter. *Chronicles the Voyager mission to Jupiter, 1972-1979, especially the "flybys" of Jupiter which occurred on March 5 and July 9, 1979, and discusses the findings. Includes many color images of Jupiter and its moons and photographs of the spacecraft and the scientists.* 1980: 211 p.; ill.
NAS 1.21:439 S/N 033-000-00797-3 9.00

Voyager at Saturn (Lithographs). *Contains 5 lithographs, each with the main title: "Voyager at Saturn." Posters have subtitles: "The Planet," "The Rings," "The Satellites," and "Titan." One poster has no subtitle.* 1981: 5 posters, 36x24 in. 1986-repr.
NAS 1.43:V 94/37/A-E S/N 033-000-00831-7 8.00

Voyager at Uranus: 1986. *Describes the Voyager 1 and 2 Mission with an emphasis on Voyager 2 encounter with Uranus January 24, 1986.* 1985: 16 p.; ill.
NAS 1.12/7:400-268 S/N 033-000-00955-1 1.25

Voyager Encounters Jupiter. *Contents of publication: Introduction; images of Jupiter and its satellites taken from Voyager 1 and 2; Voyager mission; and scientific highlights.* 1979: 40 p.; ill. 1985-repr.
NAS 1.12/7:400-24 S/N 033-000-00772-8 3.50

Voyager Flights to Jupiter and Saturn. *Discusses the Voyager Flight Project also known as the Grand Tour. Includes full-color pictures of the spacecraft and photographs of Saturn and Jupiter taken by the satellite during its mission.* 1982: 62 p.; ill.
NAS 1.19:191 S/N 033-000-00854-6 5.50

Voyager Mission Highlights. *Includes the following photographs: Uranus, True and False Colors; Ariel; Uranus Montage; Uranian Rings; Uranus and Uranian Cloud. These photographs were compiled from images sent by the Voyager spacecraft between January 22 and and 29, 1986.* 1986: 6 posters, 9x11 in. or 11x9 in.
NAS 1.43:V 94/43 S/N 033-000-00981-0 1.00

Voyager Neptune Travel Guide. *Describes the Voyager mission to explore the giant outer planets of our solar system. Also contains interesting facts about the Voyager mission, both past and future; flip-page movie frames that appear in the corners of the publication; and short summaries that describe the major objectives and schedules for several space missions planned for the remainder of the 20th century.* 1989: 285 p.; ill., 2 plates in pocket.
S/N 033-000-01056-7 12.00

Voyager 1 Encounters Saturn. 1980: 40 p.; ill.
NAS 1.12/7:400-100 S/N 033-000-00817-1 3.25

Voyages to Saturn. *Provides a chronology of the observatory activities carried out by Voyager 1 and Voyager 2 spacecraft in their missions to the planet Saturn in 1980 and 1981. Includes many photographs of Saturn and its satellites.* 1982: 237 p.; ill.
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